# The Minimum Site Investigation Requirements Needed to Define Site Conditions Considering the Results of Ground Investigations and its True Reflection of Actual Site Conditions Found During Construction

by
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# Abstract

The success of civil engineering projects, whether it involves the construction of houses, bridges, roads or tunnels, depend largely on the adequate identification of subsurface conditions.

Geotechnical engineering, even in its most primitive form, has been around for hundreds of years, and unfortunately, so have geotechnical related problems. The Leaning Tower of Pisa is probably one of the oldest and most well-known examples of the problems related to uncertainty within the ground, and so, the importance of ground investigations. The geotechnical investigation aims to reduce the occurrence and impact of such problems as far as possible. Although risk inherent in the ground is inevitable, it can ideally be identified and mitigated by way of incorporating geotechnical investigations in contractual agreements. This way, thorough understanding of requirements and preparation of an adequate investigation may assist in minimising the risk as well as cost and schedule overruns on construction projects.

In South Africa, there are various national standards, codes of practice and legislation available that are intended to guide geotechnical practitioners and associated professionals in the planning and execution of adequate geotechnical site investigations. Yet, the occurrence of structural foundation failures and construction cost overruns due to inadequate investigations still occur frequently.

This research comprehensively evaluates the investigation requirements specified in regulatory frameworks, as well as the procedures that are currently being followed by geo-practitioners in the industry. The study found that the occurrence of geotechnical related failures is mainly ascribed to inadequate implementation of the regulatory framework. Furthermore, unlike related professions, there are currently no standardised specifications for geotechnical investigations.

By identifying pitfalls associated with current site investigation trends in South Africa, the study provides a basis from which the required minimum specifications can be developed and successfully incorporated as contractual obligations by means of a standardised specification.

# Opsomming

Die sukses van siviele ingenieursprojekte, of dit die bou van huise, brûe, paaie of tonnels behels, hang grootliks af van die voldoende identifisering van ondergrondse toestande.

Geotegniese ingenieurswese, selfs in sy mees primitiewe vorm, bestaan al honderde jare, en, so ook geotegniese verwante probleme. Die leunende toring van Pisa is waarskynlik een van die oudste en mees bekende voorbeelde van die probleme wat verband hou met onsekerheid in die grond, en dus ook die belangrikheid van grondondersoeke. Die geotegniese ondersoek poog om die voorkoms en impak van sulke probleme sover moontlik te verminder. Alhoewel inherente risiko in die grond is onvermydelikis, kan dit ideaal gesproke geïdentifiseer en versag word deur middel van geotegniese ondersoeke wat uitgevoer word ooreenkomstig met toepaslike wetgewing en die norme van die bedryf. Dit sal deeglike begrip van die vereistes en voorbereiding van n voldoende ondersoek verseker, en so ook help om risiko, sowel as koste en schedule oorskryding op konstruksieprojekte te vermider.

In Suid-Afrika is daar verskeie nasionale standaarde, praktykskodes en wetgewing beskikbaar wat beoog om geotegniese praktisyns en geassosieerde professionele persone te lei in die beplanning en uitvoering van voldoende geotegniese terreinondersoeke. Tog is die voorkoms van strukturele grondslagfoute en konstruksiekoste-oorskryding as gevolg van onvoldoende ondersoeke steeds n gereelde verskyning.

Hierdie navorsing evalueer die ondersoekvereistes in regulatoriese raamwerke, asook die prosedures wat tans deur geo-praktisyns in die bedryf gevolg word. Die studie het bevind dat die voorkoms van geotegniese verwante mislukkings hoofsaaklik toegeskryf word aan onvoldoende implementering van die regulatoriese raamwerk. Verder, in teenstelling met verwante beroepe, is daar tans nie gestandaardiseerde spesifikasies vir geotegniese ondersoeke nie.

Deur identifisering van tekortkominge wat geassosieer word met huidige terrein ondersoek neigings in Suid-Afrika, bied die studie 'n basis waarvan die vereiste minimum spesifikasies ontwikkel kan word en suksesvol as kontraktuele verpligtinge by wyse van 'n gestandaardiseerde spesifikasie opgeneem word.

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# Chapter 1: Introduction

"Projects we have completed demonstrate what we know, future projects decide what we will learn."

- *Dr Moshin Tiwana*

## 1.1 Background to Study

Research published by several sources, from as long as over thirty years ago, illustrates and concludes that the largest element of technical and financial risk in civil engineering projects lies within the ground (National Research Council, 1984; Institution of Civil Engineers, 1991; Littlejohn et al., 1994 and Whyte, 1995). The discovery of unexpected subsurface features during construction can lead to project delays, design changes and unplanned and expensive construction works. Cost and schedule overruns on large civil engineering projects are typically the effect of unforeseen geological conditions and associated geotechnical problems. "Despite numerous attempts to deal with these situations, such as incorporating various clauses in contract documents, the problems persist" (Hoek & Palmieri, 1998).

Geotechnical engineering has been a topic of great interest for centuries. Excellent progress has been made in terms of research over the years, with significant contributions from South African researchers. The emphasis has however not been placed upon the minimum geotechnical investigation requirements for different types of developments. The specification of the minimum extent of fieldwork and laboratory testing will ensure a realistic assessment of the subsurface conditions and provide relevant input data on the basis of which realistic engineering decisions can be made.

This research is inspired by the increased demand in infrastructure due to a rapidly growing population in South Africa. Although the construction sector is growing, there seems to be no accompanying growth in the investment in, and quality of geotechnical investigations. By using at least, the minimum sampling or exploratory requirements needed to define site conditions as accurately as possible, the quality and success of civil engineering projects will increase and construction costs and failures will be reduced significantly.

## 1.2 Problem Statement

A poor geotechnical investigation typically results in the collection of insufficient geotechnical data, which is the main cause of project delays, disputes, claims, and project cost overruns and failures (Temple & Stukhart, 1987). According to Osterberg (1979), site investigation can be considered a failure if it does not accurately reveal subsurface conditions needed for safe economical design of foundations or earth structures.

Although geotechnical investigation requirements are set out in various national standards, codes of practice and legislation, structural foundation failures and construction cost overruns due to inadequate investigations still occur frequently.

## 1.3 Contribution of Research

There are various national standards, codes of practice and legislation available that are intended to guide geotechnical practitioners and associated professionals in the planning and execution of adequate geotechnical site investigations. The knowledge, techniques and equipment required to carry out investigations in accordance with these codes exists. The fact that construction and project failures still occur rather frequently, is an indication that these codes are not being implemented.

Part of the reason why these codes are not being implemented lies in the manner in which geotechnical investigations are procured. All too often, a tender (or enquiry / request for proposal) is issued with no accompanying specification of minimum requirements for such an investigation. As a result, widely varying bids are received and, all too often, the only yardstick on which these bids are adjudicated is price.

It is clear that there is a need to investigate means whereby minimum requirements for geotechnical investigation can be conveniently specified for different types of developments in much the same way as a quantity surveyor would use a standardised specification such as SANS 1200 to set minimum requirements for construction works. Adequate specification of the correct investigation requirements from the start will go a long way to establishing improvements in the quality of the geotechnical investigations.

The findings of this research are not sufficiently detailed to be incorporated into revisions of national standards and codes of practice. However, the findings have the potential to mitigate construction and project failures caused by inadequate geotechnical investigation by means of identifying pitfalls associated with current site investigation trends in South Africa and provide a basis from which the required minimum specifications can be developed. It may also offer young, inexperienced practitioners and non-geotechnical members of the project team the opportunity to become acquainted with minimum investigation requirements applicable to different types of developments and provide a basic understanding of the specific procedures to be followed when doing specialised investigations for different types of projects such as development of dolomite land, basement excavations, piled foundations, etc.

## 1.4 Research Objective

The main objective of the research study is to critically assess shortcomings in geotechnical investigation practices and the need for minimum site investigation requirements in South Africa, that are essential to accurately define site conditions for different types of development. It will also identify and illustrate the pitfalls of current practice by means of case studies of inadequate investigations. It will conclude by recommending changes needed in the future.

The following specific objectives were formulated with the goal of achieving the main objective:

i. To provide an overview of the various components of a geotechnical investigation and an overview of the requirements of legislation, codes and standards in South Africa.

ii. Demonstrate the consequences of inadequate investigations as a result of non-compliance of the geotechnical regulatory framework.

iii. Propose revisions to codes, standards and legislation to improve project success and reduce contractual claims and disputes arising from inadequate investigations.

iv. Produce an initial draft of a standardised specification for geotechnical investigations of residential townships and housing.

The purpose of this study is to create a comprehensive methodology that will guide South African engineers and engineering geologists in conducting adequate geotechnical investigations and provide related professions with the means of specifying an appropriate scope of work when calling for proposals for such investigations. Research questions that relate to the study include, but are not limited to:

i. What combination of field investigation techniques and specifications are the most effective in terms of quality of information gained and its influence on adequately determining subsurface conditions?

ii. What are the minimum site investigation requirements to accurately define soil conditions and identify potential geotechnical hazards, including problem soils?

iii. Why do the actual site conditions often differ from what was found during the geotechnical site investigations and what are the potential consequences of these differences?

The study further aims to provide an understanding of what the minimum geotechnical investigation requirements for different types of development are and what aspects needs to be avoided and improved to achieve satisfactory investigation results.

## 1.5 Research Methodology and Report Layout

The research is based on a qualitative approach that relies on information and data available from geotechnical practitioners that have substantial experience from working in the industry for many years. Data gathered for this study comprise information and reports on investigation failures relating to specific types of developments, presented as case studies. A comprehensive evaluation of the investigation requirements specified in regulatory frameworks, as well as the procedures that are currently being followed by geo-practitioners in the industry form the core of this research.

The case studies highlight foundation and project failures and how these relate to the effectiveness or otherwise of the geotechnical investigation requirements set out in national standards, codes of practice and legislation. The aim of the review is to provide insight to the intended outcomes these regulatory frameworks, to determine the degree of compliance therewith and identify areas of concern regarding their implementation.

For ease of reference to the reader, a brief overview of the contents and objectives of each chapter is given below.

<u>Chapter 2: Literature Review</u>

The literature review comprises an overview of the history of geotechnical engineering at both national and international levels. The idea is to demonstrate and emphasize that the need for site investigations was recognised hundreds of years ago.  In this chapter however, the focus is mainly on geotechnical investigations. Relevant existing information from various sources was gathered and reviewed to lay the foundation of this research. Important aspects of the site investigation, including various methods of investigation, different phases of investigation and investigation cost are discussed, accompanied by examples relevant to the South African industry. Attention is paid to how these aspects relate to one another. The chapter is therefore written as to tell a story to inexperienced and non-geotechnical practitioners, helping them to gain an appreciation of the geotechnical site investigation process.

<u>Chapter 3: The regulatory framework for geo-professionals in South Africa</u>

This chapter introduces the regulatory documents that set requirements for geotechnical investigation in South Africa. As part of the summary relating to the objectives of each document, it is pointed out how the geotechnical investigation forms part of these regulations by referring to specific clauses that deal with site investigations. This forms the base for the specific investigation requirements that are discussed in more detail in the following chapter. Furthermore, the effects of inadequate investigations are discussed, leading to the legal and professional responsibility that rests upon geotechnical practitioners and associated professionals who fails to carry out adequate investigations.

Chapter 4: Specific requirements for various categories of development

Specific geotechnical investigation requirements for various types of development including townships, houses, linear structures, pile foundations, lateral support and developments on dolomite land are set out in detail in Chapter 4. The applicable standards, objectives and specific requirements for these developments are described with reference to the specific clauses, sections, chapters and tables that lay down the minimum site investigation requirements needed to adequately define subsurface conditions. The aim is to extract all the geotechnical site investigation requirements specified in various documents, to incorporate and organize it according to the applicable types of developments.

Chapter 5: Case Histories

Chapter 5 presents the analysis of cases histories from real projects that highlight the effects of inadequate site investigations. The review of multiple case studies can be regarded as an all-inclusive case study that illustrates current site investigation shortcomings in practice. These case studies illustrate the fundamental problems facing geo-practitioners, and extract lessons and principles that can be applied in the industry to improve the quality of geotechnical investigations. The findings of this chapter form part of the integrated conclusion, where recommendations will be proposed in the last chapter.

Chapter 6: Conclusions and Recommendations

The research findings are summarized and combined to formulate concise conclusions. These conclusions were drawn by integrating the literature review with the findings of the case study review and analysis of the regulatory framework. Conclusions drawn from each of the case studies under the various categories of development are elaborated in this chapter.

Furthermore, recommendations for change, which may offer possible solutions to the research problem stated above, are given. The proposed recommendations form part of an extensive solution strategy to address the occurrence of foundation and project failures and improve the quality of geotechnical investigations in South Africa.

# Chapter 2: Literature Review

"Unfortunately, soils are made by nature and not by man, and the products of nature are always complex…"

- *Karl von Terzaghi, 1936*

## 2.1 Introduction

Like many common words, the word *soil* has several meanings and is defined in accordance with the field of study, from micro-scale in Soil Biology to macro-scale in Geology. For engineering purposes, soil is defined as un-cemented or weakly cemented accumulation of mineral particles and/or organic matter with water and air contained in the void spaces between particles (Knappett & Craig, 2012:3). Sometimes it is even described as the solid material that can be removed without blasting. However, it needs to be considered that soil is a natural material that has been derived from the weathering or disintegration of various types of rock, some of which are about 4 billion years old. Therefore, the geotechnical materials on each site are the unique products of many influences including geological origin, age, tectonic environment, past and present climates, topography, vegetation and the influence of man (Day, 2013). Taking all the above factors into account, there are many risks in the ground which have been inherited from its past.

As in Clayton, Matthews and Simons (1995:1):

> "Because deposition is irregular, soils and rocks are notoriously variable, and often have properties which are undesirable from the point of view of a proposed structure. Unfortunately, the decision to develop a particular site cannot often be made on the basis of its complete suitability from the engineering viewpoint; geotechnical problems therefore occur and require geotechnical parameters for their solution."

The process of acquiring geological, geotechnical, and all the relevant information needed to determine the engineering properties and design parameters for construction of a planned development, is referred to as the geotechnical investigation or site investigation. A geotechnical investigation is the first step towards a successful project and is a critical part in managing risk, in terms of safety and cost. Although the need for site investigations is self-evident, the process and relevance thereof is often not fully appreciated by inexperienced engineering geologists and geotechnical engineers, nor by members of associated professions such as structural engineers, quantity surveyors and project managers who are often required to specify and procure geotechnical investigations. Questions frequently asked regarding geotechnical investigations includes the following: What is a site investigation, why is it relevant and what does the planning of such investigations entail? What type of methods are being used? What type and how many samples should be collected and what type and how many tests should be done?

This chapter gives an overview of the evolution of geotechnical engineering and aims to answer most of these questions and describe the process of conducting a geotechnical investigation. It also aims to explain how the different components of a site investigation interact and connect. Most sections focus on, or make use of, scenarios and examples that involve geotechnical engineering in South Africa.

## 2.2 Historical overview of geotechnical engineering

Geotechnical Engineering is a sub-discipline of Civil Engineering which is concerned with the engineering behaviour of natural materials found on or close to the earth's surface. It includes, amongst other, the investigation, analysis, design and construction of various structures and systems that are made of or are supported by soil or rock. Although this discipline, in its present form, is relatively young, interest in the behaviour of soil and rock for engineering purposes can be traced back to Roman times (Plommer, 1973), and numerous structures (buildings, roads, bridges), some still standing today, are proof that some knowledge and understanding of earth's materials existed among ancient civilizations. However, Das (2010:1) stated that the record of a person's first use of soil as a construction material is lost in antiquity.

"Mathematical solutions to geotechnical problems have been around for centuries" (Day, 2013), and according to Murthy (2002), geotechnical engineering has passed in succession through two stages; the empirical stage and the scientific stage. Several notable contributions have been made by French engineers from as early as 1717, when Henri Gautier studied natural slopes in soils. His original study was followed up by Bernard Forest de Bélidor who proposed a theory for lateral earth pressure on retaining walls in a textbook he published in 1729. Francois Gadroy studied the existence of slip planes in soil at failure and in 1746, he reported test results on the first laboratory model of a retaining wall that was 76 mm high and built with sand backfill. Around 1769 Jean Rodolphe Perronet, who studied slope stability, distinguished between intact ground and fills (Das, 2010).

It is, however, Charles-Augustin de Coulomb (1736 - 1806) that was credited for making the first major contribution with his work done on retaining structures which was published in 1776 by the French Academy of Sciences. Coulomb's work showed considerable understanding of soil as an engineering material. Subsequent papers, principally delivered by the French, did much to refine the available solutions but little to increase fundamental knowledge (Clayton, Matthews and Simons, 1995 and Das, 2010).

The development of Geotechnical Engineering took a huge turn in the 20th century when Karl von Terzaghi (1883 – 1963) developed the theory of effective stress which was published in his book Erdbaumechanik in 1925. Soil had been treated as a single-phase solid in all preceding work. Terzaghi was the first person who identified saturated soil to be a two-phase material consisting of soil grains and pore water, and partially saturated soil as a three-phase material where the pore spaces contains both water and air (Donaldson, 1985). Therefore, he became the first to elaborate a comprehensive mechanics of soils, and became recognized as the leader of the new branch of civil engineering called soil mechanics. Terzaghi is known today as the "father of modern soil mechanics".

## 2.3 Geotechnical Development in South Africa

It is no secret that South Africa has some of the most beautiful landscapes in the world. Some of these "wonders" may still be undiscovered. However, exploration of the land started from as early as when Cape settlers started moving inland. With South Africa's complex geological history dating back millions of years, moving could not have been an easy task. These pioneers' engineering skills were put to the test by the need to cross mountain ranges and escarpments to reach the interior of the country (Donaldson, 1985).

The achievements of Scottish born, Andrew Geddes Bain (1979 – 1864) called attention to the ways in which the skills and science of geology and engineering progressed over the centuries. Bain arrived in the Cape in 1816 and since then, was a keen explorer. Along with his family, he moved to Graaff-Reinet, and in 1832 he was awarded a medal for the gratuitous supervision of the construction of the Van Ryneveld's Pass near the town (Day, 2013). However, the magnum opus of Andrew Geddes Bain is the pass that bears his name, the Bainskloof Pass which crosses the Limietberge between Wellington and Ceres. It is a work of considerable engineering complexity that has become one of the most scenic routes in the Cape. With no formal training in engineering, Andrew Bain constructed eight major passes in South Africa.

Bain also developed an intense interest and expertise in geology which led him to produce the first comprehensive geological map of South Africa. The map was published by the Geological Society of London. After such meaningful work in this field, he has been hailed as 'the father of geology' in South Africa. His son, Thomas Bain, who served a six-year' traineeship under him, attained a reputation as a locator, designer, builder and supervisor of the construction of mountain passes in the Cape (Ross, 2004). Thomas Bain constructed a further twenty-four passes during his career as a road builder (Storrar & Komnick, 1984). The impressive dry-stone retaining walls still seen in the Swartberg Pass in the Western Cape are said to be the trademark of Bain Jnr. The father-son combination of Andrew and Thomas is broadly known for their major influence on road construction in the Cape Colony during the 19$^{th}$ century.

Motivated by the need for various infrastructure, soil mechanics developed in South Africa as much as in other countries. Engineering geology in South Africa received international recognition during the 1930's and 1940's (Korf and Haarhoff, 2007), when Jeremiah "Jere" Jennings (1912 – 1979), a geotechnical engineer, astounded this discipline with his phenomenal achievements.

In the same way as Terzaghi is regarded as the father of modern soil mechanics, Jennings can certainly claim this title in his native South Africa (Day, 2013). Jennings obtained a BSc degree in civil engineering from the University of Witwatersrand at the end of 1933. While doing vacation work as a student, he was introduced to the theories of compaction, which also awakened his interest in soil mechanics. He wrote his first paper, '*A few notes on earth dams and the soil mechanics related thereto*' was published in the Journal of South African Institution of Engineers in October 1935. According to Donalsdon (1985) this was possibly the first paper ever on this specific subject to be published in South Africa.

Jennings gained his MSc degree in engineering from the Massachusetts Institute of Technology (MIT) where he studied soil mechanics under Terzaghi. Thereafter, he returned to South Africa and joined the South African Railways and Harbours as a junior engineer in the research section. He was then invited to join the National Building Research Institute (NBRI) of the Council for Scientific and Industrial Research (CSIR) in Pretoria, as head of its engineering department.

Jennings attracted several promising young engineers to join the staff, including Basil Kantey, Keeve Steyn, Lou Collins, George Donaldson, Ken Knight and Tony Brink (Day, 2013). During this time, the country was confronted with many geotechnical challenges such as expansive and collapsible soils which caused cracking of buildings and sinkholes initiated by dewatering of dolomites. This period saw the greatest advances in South Africa by means of remarkable research by Jennings and his team that could also apply in other parts of the world. Jennings also inspired the introduction of engineering geology and soil mechanics in both undergraduate and postgraduate degree courses when he was appointed as a professor at the University of Witwatersrand.

Another influential pioneer was A.B.A (Tony) Brink (1927 – 2003), an engineering geologist. After obtaining a BSc (Geology) degree at the University of Pretoria in 1948, Brink's career took an important turn when he started working at the NBRI under Jennings (Korf and Haarhoff, 2007).

By sharing the beliefs of Terzaghi, Jennings and Bain, Brink accomplished exceptional achievements among which the "Brink Books", a series of four books entitled Engineering Geology of Southern Africa Volumes 1 to 4, published between 1979 and 1985, was his magnum opus. In short, the first two books of this four-volume series focus on the engineering characteristics of rocks and their weathered derivatives that was formed between 4 000 and 300 million years (Ma) ago. The third volume deals mainly with the engineering properties of rocks from the Karoo Sequence aged 300 Ma and less, and the final volume focus on transported soils which occur throughout the Southern African region. Day (2013) describes the Brink books as an invaluable guide in the planning of geotechnical investigations and interpretation of the results, providing a broad overview of the engineering geology of the region and the type of problems likely to be associated with individual strata. These books also provide numerous case studies that are of great help with geotechnical investigations.

In addition, it was also Tony Brink who "discovered" the Pebble Marker which is defined by Brink and Bruin (1990) as the gravelly soil which forms the demarcation between the transported soils which overlie it, and the country rock or residual soils below. This makes it an important marker enabling the profiler to define the transition from transported to residual soils (Korf and Haarhoff, 2007). Brink played a pivotal role in developing the "MCCSSO" (moisture, colour, consistency, structure, soil type and origin) nomenclature for the description of soils which still forms the basis of modern-day description of soil profiles in South Africa. According to Day (2013), the guide to soil profiling by (Jennings, Brink &Williams (1973) is probably the most influential geotechnical paper published in the country to this day.

## 2.4 Recent (practical) Geotechnical Advances in South Africa

One of the more recent major infrastructure developments in South Africa is the approximately 80 kilometre, state-of-the-art, rapid rail link known as the Gautrain. The route includes two links, the shorter link between OR Tambo International Airport and Sandton, and the longer link from Tshwane (Pretoria) to Johannesburg. Challenging ground conditions were encountered along several sections of the route. These included dolomite formations that is prone to sinkhole formation towards the northern end between Tshwane and Centurion, very hard rock quartzite and shale formations that slowed down the tunnelling processes substantially and very deeply weathered granite with a collapsible grain structure around Sandton and Rosebank areas. Geotechnical investigations were done in detail using different ground investigation methods and suitable solutions were found for all the challenges making the Gautrain project one of the biggest geotechnical milestones in the country.

Another major successful project was the construction of the new Sasol building in Sandton, Gauteng. The building spreads over approximately 60 000$m^3$ and comprises 11-storeys with a height of about 47m. To be expected, this project also had some geotechnical challenges. "Of the total excavation of 60 000$m^3$, no less than 20 000$m^3$ was extremely hard, un-weathered granite which required extensive drilling and blasting" (Franki Africa, 2017). In addition to the hard rock, a dolerite dyke was encountered on parts of the site that required a change to the proposed piling technique, extending the construction time. Despite all these challenges, the building was constructed successfully. Both these projects enhanced the development of various geotechnical techniques including ground improvement and ground anchoring technology. It also developed the field of geotechnical contracting significantly.

## 2.5 The Geotechnical Investigation

Site investigation involves gathered all relevant information concerning the site of a proposed development and its surrounding areas (Simons, Menzies & Matthews, 2002). The investigation process also includes analysing and assessing data that has been gathered to be presented in the form of a report.

The purpose of the geotechnical investigation is amongst other to determine the sequence, thickness and extent of soil and rock types and groundwater conditions, conduct in situ field testing to assess soil characteristics, and obtain representative samples for laboratory testing. Data obtained during the investigation is then used to determine the in-situ state of the soil and rock and evaluate the chemical properties thereof, as well as material parameters such as particle size distribution, strength, compressibility, moisture content and unit weight of soils. It is important that data obtained from site investigations essentially identify factors that critically effect the safe performance of structures. Another important parameter is excavatibility. Materials that cannot be excavated with conventional excavation equipment require blasting or hydraulic hammers for excavation, which contributes to an increase in project cost.

There is no doubt that site investigation is no longer a guessing game. Although the objectives of investigations may be the same, various approaches are being taken to undertake a geotechnical investigation. Because the geotechnical investigation is such a complex process, it is easy to get confused with the detail of and technicalities involving the investigation process, therefore, it is important to have a general approach to undertaking ground investigations. A four-stage-approach that contain the major component is shown in and described below.

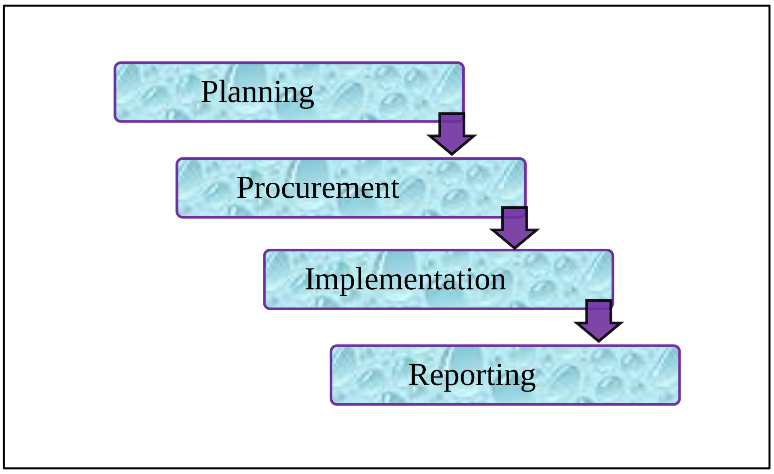



*Figure 2.1: The four-stage-approach to geotechnical investigations.*

### 2.5.1 Planning

Planning is an essential part of the investigation process. Good planning for of a geotechnical site investigation is the key to obtaining sufficient and correct site information for designing a structure in a timely manner and with minimum cost for the effort needed. During this stage, all fundamental and relevant information on both the site and the proposed development need to be gathered. It is the responsibility of the geotechnical consultant to ensure that the client clearly communicates the scope and detail of the project to start the planning process of the investigation. With this information, the appropriate investigation methods can be determined. For test pits, the number and depth of the pits need to be assessed to determine whether a tractor-loader-backhoe (TLB) will be sufficient or an excavator will be required. Borehole positions needs to be planned to assess access requirements for rigs on site. Many sites are underlain by services such as electrical and telecom cables and water pipes and detailed drawings showing all services should be obtained to assist in positioning test pits and boreholes. Planning also includes deciding what type of samples to take and the appropriate tests to be carried out both in the field and the laboratory.

Additionally, Occupation Health and Safety must be considered. Depending on the type of project, planning needs to be made among other in terms of travelling, working in excavations and protection of animals in the field.

It is frequently required that the geotechnical engineer provide the client with a schedule showing time frames in which various tasks will be completed.

### 2.5.2 Procurement

In the United Kingdom, it has been widely considered that prudent procurement of the investigation is the key to obtaining a good site investigation at a reasonable price (Clayton, Matthews and Simons, 1995). Project procurement documentation should include information determined during the planning stage, such as site access, number and depth of test pits and or boreholes and the type and amount of testing. In most instances, the client will appoint a geotechnical consultant to undertake the investigation. The appointed consultant will appoint sub-contractors to supply equipment such as TLB's or excavators, drill boreholes or undertake specialist field testing such as geophysical work, plate load tests, etc. Laboratory testing is undertaken by commercial laboratories. The appointed geotechnical consultant takes responsibility for preparing specifications and bills of quantities for these sub-contractors which may form the basis of a direct appointment or a tender process.

The appointment of a consultant may by a sole-source (direct) appointment, preferred bidder tender or open tender (SAICE, 2010). In the first two instances, the consultant will normally be responsible for determining the scope of the investigation. In the case of open tenders, the scope of work must be clearly specified to ensure competitive bidding and the adequacy of the final product.

According to (Ngobeni, 2011), in South Africa, the factors considered in the appointment of a geotechnical consultant include quality, suitability, price, abilities of the bidder as well as the supply reputation and financial standing.

The appointment of any consultant should always be in writing. Standard conditions of contract that clearly define the duties and responsibilities of all parties involved, state liability for each party and state the means whereby disputes are to be dealt with, are normally used.

The SAICE Site Investigation Code of Practice (SAICE, 2010) lists the most commonly used conditions of contract for consulting services in South Africa as:

- New Engineering Contract: The Professional Services Contract, Third Edition, June 2005. Institution of Civil Engineers, London. Thomas Telford Limited, London.
- FIDIC Client - Consultant Model Service Agreement, Fourth Edition, 2006. International Federation of Consulting Engineers, Paris.
- CIDB Standard Professional Services Contract, Second Edition, September 2005. Construction Industry Development Board, Pretoria.
- SAACE Form of Agreement for Consulting Engineer Services, July 2003. Consulting Engineers South Africa (CESA), Johannesburg.

The Construction Industry Development Board (CIBD) further lists the following recommended forms of contract (CIBD, 2005):

- FIDIC (French acronym for International Federation of Consulting Engineers) 1999.
- General Conditions of Contract for Construction Works (GCC 2004).
- JBCC Series 2000.
- NEC3 family of standard contracts.

"The FIDIC, NEC and GCC can be used on all types of engineering and construction contracts. The JBCC 2000 is, however, confined to building works. The FIDIC, NEC and JBCC documents contain short versions of engineering and construction works contracts." (CIBD, 2005). If the FIDIC or NEC documents are used, the consultant should be appointed using the professional services contract included in each suite of documents. The JBCC 2000 and GCC contracts are for construction works and are generally not suitable for the appointment of a geotechnical consultant.

Geotechnical investigations generally involve the drilling of holes or formation of excavations. As such, they are classified as construction activities in terms of the Occupational Health and Safety Act, 1993 (Act No. 85 of 1993). The investigation must therefore be carried out in accordance with the requirements of the Act and of the Construction Regulations (2014) (Department of Labour, 2014). The Act places specific obligations on the employer and the employee while the Regulations spell out the duties of the client, the designer and the contractor. One of the requirements is that all the people who are working on a construction site or with construction equipment need to have a valid medical certificate of fitness as proof that they went through a medical assessment and were declared fit to do the work.

The preparation of a baseline risk assessment and a health and safety specification by the client forms part of the procurement stage in the four-stage approach described above.

### 2.5.3 Implementation/Execution

The execution stage focusses largely on the actual site investigation in the field. The responsibility rests upon the person conducting the field investigation to ensure the quality of the work undertaken and of the data obtained. It is important for the geotechnical engineer or engineering geologist to familiarise themselves with the techniques and objectives of the investigation. As a recommendation, the geotechnical engineer or engineering geologist should do the following while on site:

- Clearly communicate the purpose of the investigation to all parties (drillers, TLB operators, foremen, etc.) and make sure everyone knows what is expected of them.
- Make sure that the correct techniques are used, and that the equipment complies with the specifications.
- Closely watch drilling and sampling techniques to make sure disturbance of soil is minimized and that representative samples are obtained from all soil horizons.
- Frequently check the driller’s borehole records for authenticity and accuracy.
- Liaise with the structural design engineer, so that the investigation can be modified if needs be.

Take note that the size of the investigation will determine the number of geotechnical engineers and engineering geologists that will supervise the work on site, since it will be difficult for one person to supervise multiple activities at the same time.

Another important factor during the execution stage is Occupational Health and Safety (OHS) on site. All persons (whether on site every day or just visiting for a couple of hours) should, before starting work go through a site safety induction. The purpose of the induction is site specific, but in general it aims to ensure that all persons entering the site are fully informed about the activities on site as well as particular risks and hazards on the site. It focusses on safety aspects and emergency procedures. In case of a geotechnical investigation, there are often services such as electrical cables in the area, and all persons on site should be aware of the location of such services and should know what to do if one of these services are struck by a drilling rig or excavator.

By adhering to the above recommendations, results of higher quality field data and safe practice can be ensured.

### 2.5.4 Reporting

Reporting is a method of communication; therefore, the findings of the site investigation must be clearly communicated by the geotechnical report. The report should include a description of the stratigraphy of the ground, identification of problematic conditions, a prediction of behaviour of the ground relevant to the proposed works and recommendations to the designer. Therefore, the geotechnical report should ideally be produced prior to design and construction. Different companies/clients use different report layouts, however, the presentation of information obtained via site investigations should always be presented in a logical and orderly manner. The structure of the report depends largely on the type and size of project as well as the client's preference, for example, the focus and structure of a report for linear structures (roads, tunnels and pipelines) will be different to that of a compact structure (a house or other small structures). Some clients prefer to receive a draft version of the report which they can review prior to finalisation. Clients may also wish to separate the factual report from the interpretative report. This gives them the option to issue only the factual report to the contractor leaving the interpretation of the data to the contractor in an attempt to limit risk. Notwithstanding, a good geotechnical report should always include (SAICE, 2010):

- Introduction: terms of reference, abbreviations and symbols, purpose and scope, proposed development and available information,
- Factual information: location and description of site, regional geology, investigation procedures used and factual data obtained,
- Interpretive information: site stratigraphy, material properties, geotechnical constraints and design recommendations, and
- Appendices: references, test results and drawings.

## 2.6 Investigation Methods

There are various approaches to conducting a site investigation, depending on, amongst other, the purpose and extent of the investigation. However, for an investigation to be successful, it is important that the correct methods are being used and that results are interpreted correctly. Therefore, substantial knowledge and experience are often required.

This section gives a short description of the various methods of investigation. Note that not all investigation methods are discussed, but only the ones that are in common use.

### 2.6.1 Non-intrusive Methods

#### 2.6.1.1 Remote Sensing

Remote sensing is an effective investigation method used throughout construction projects. It may form a critical part of the desk study in the early stages or can be used for monitoring during the construction and maintenance stages of a project. During the planning stage, this method is essentially used to collect geotechnical and environmental data by using sensing devices that are not in physical contact with the earth. However, it is required to understand the underlying geology and geotechnical characteristics when interpreting remote sensing data. The use of remote sensing can provide the investigator with an overview of the project area on both small and large scales. With this type of information, successful planning of the site investigation can commence. As a very simple example, it can be used to assess the accessibility to drilling, excavating or other necessary plant of the site for carrying out the investigation. It is also useful to have an idea of the geological and geotechnical conditions to help with the planning of drilling or sampling.

Examples of remote sensing in common use include GoogleEarth (satellite) imagery, stereo-paired aerial photos, airborne geophysics, etc.

#### 2.6.1.2 Geophysical Methods

Geophysical methods are an efficient and cost-effective technique used to obtain subsurface information during geotechnical investigations. These methods hold the advantage of exploring relatively large areas to obtain data which can then be used for establishing soil and rock stratification, and for determining geotechnical properties (Massarch, 2000). There are various parameters that can be measured by geophysical methods and some of the materials that can be detected includes geological materials, chemical substances, construction material, water and voids. The most commonly used geophysical methods for site investigations includes Continuous Surface Wave tests, Ground Penetrating Radar, Magnetic, Electromagnetic, Gravity, Resistivity and Seismic surveys.

Although non-intrusive (surface) geophysical surveys are more commonly used for site investigations, geophysical tests can also be performed intrusively in the form of downhole/borehole surveys. Geophysics is a specialised field that requires adequate knowledge and understanding of the various methods as well as how to apply them. The geophysical surveys should therefore be conducted by a specialist geophysical contractor that has sufficient experience and judgement to interpret the results.

### 2.6.2 Intrusive Methods

#### 2.6.2.1 Test holes / Soil Profiling

The excavation, profiling and sampling of test pits, also known as trial pits, is an extremely effective and commonly used method to obtain subsurface information on a potential construction site to depths of 3m for tractor-mounted loader/backhoes (TLBs) or 5m – 6m for larger excavators.

Profiling of the hole involves recording a full description of each layer in the profile in terms of the MCCSSO convention (moisture condition, colour, consistency, structure, soil type and origin). These parameters are most accurately described from fresh soil, therefore, the observer should where it is safe to do so try to log the pit immediately after excavation before the soil has dried out. The presence or absence of groundwater (seepage, perched water table or permanent water table) should always be recorded and particular caution should be exercised where water seepage into test pits could destabilise the sidewalls. Additionally, information such as termination depth, the reason for termination and the material in which the pit was terminated are important when logging test pits. When taking samples, sufficient quantity of sample of the appropriate type (disturbed or undisturbed) should be taken for the tests required at the appropriate depths. The sample number, depth, test pit number and type of sample must be recorded on both the sample label and the pit log.

In South Africa, soil profile logging should be carried out in accordance with ***Guidelines for Soil and Rock Logging in South Africa*** manual (Brink and Bruin, 1990) which is an updated version of the paper titled ‘Revised guide to soil profiling for civil engineering purpose in South Africa’ (Jennings, Brink and Williams, 1973).

It is of utmost importance that all inspections carried out in test pits are done in a safe manner and that great care should be taken in and around excavations. Safety First! Guidelines are given in the SAICE code of practice for the safety of men working in small diameter shafts and test pits for geotechnical engineering purposes (SAICE, 2007).

#### 2.6.2.2 Geotechnical Drilling

Geotechnical drilling is an intrusive method that is commonly used to obtain a representative soil and rock samples at depth below the ground surface to determine site characteristics. Although geotechnical drilling is commonly used for site investigations, it is also required when ground stabilization methods such as anchoring, grouting and soil nailing are being applied during the construction phase of a project. Various drilling methods exists, each has advantages and disadvantages. It is therefore important that the size, type, purpose and other specific requirements of the project be considered before deciding which method will be most appropriate. “Inappropriate means and methods may in fact worsen the ground properties or structural conditions the construction technique is intended to enhance" (Bruce, 2003). Geotechnical drilling requires significant skills, knowledge and experience. It is thus important that the services be carried out by a specialised drilling company that can provide the correct equipment and qualified operators.

There are three drilling methods that are commonly used in South Africa.

**Auger Drilling** for site investigation is the process of drilling large diameter (usually 750mm) holes into the ground by using a flight auger. Although this method is economical and fast, holes in cohesionless soils or in soils below the water table are prone to collapse and the auger may not be able to penetrate cemented soils or hard rock. Auger holes can reach depths 36m or more below NGL with the larger auger rigs. The hole is profiled and sampled by lowering a qualified and experienced engineering geologist or geotechnical engineer down the hole in a bosun's chair. This type of profiling is being used less in the industry due to safety concerns such as sidewall collapse.

**Core Drilling** involves rotary drilling using hollow rods attached to a core barrel. Various types and sizes of core barrels are used, with either diamond or tungsten cutting bits. The most popular size of core barrel in South Africa is an N-sized barrel (76mm diameter hole, 50mm diameter core – in round numbers). Core samples are contained in a tube inside the core barrel with the most popular barrel being the double tube, split inner tube, NWD4 barrel. The aim is to retrieve fully intact cores that are representative of how the strata is layered. This type of drilling can be used in virtually all soil and rock types. Rock core samples often shows discontinuities such as joints, cracks and fissures that are of utmost importance to the engineering geologist or geotechnical engineer. Temporary casing may be installed where necessary. SPT tests and other in situ tests can be carried out in the boreholes.

**Percussion Drilling** is a means of quickly producing a borehole that provides disturbed samples (chips) to be logged by an engineering geologist or geotechnical engineer. Holes are typically 125 – 225mm in diameter and are drilled using a down-the-hole rotary percussion hammer. As part of collecting geotechnical data, the drilling parameters such as the penetration rate (seconds per metre), air loss, sample return, hammer tempo and groundwater strikes recorded as drilling proceeds. Automated recording systems are available that record additional parameters such as air pressure, torque, etc. Percussion chips flushed from the hole are collected on surface for each metre drilled.
Percussion drilling is suitable for both consolidated and unconsolidated formations and is perfect to be used when drilling needs to be done on hard material such as rock. However, the chips produced may be contaminated from contact with other material in the hole while blown up annulus between the sidewall of the hole and the drilling rods, lowering the quality of samples. Casing may be installed as drilling progresses.

### 2.6.3 In-situ Test Methods (Field Testing)

In-situ tests are done in the field. They are a means of testing subsurface material in-place, meaning the material has not been moved from its original place of deposition. The tests are done using instruments that can penetrate the ground to measure the nature, behaviour and characteristics of subsurface strata as well as the ground water conditions. As opposed to trail pits and boreholes, in-situ tests hold the advantage of being carried out on material that has not undergone sample disturbance. However, in most cases samples are not obtained, meaning there is nothing to compare test results to. Thus, in situ testing is generally combined with rotary core drilling or other methods of investigation. The interpretation of these methods also requires substantial knowledge and experience.

There are various in-situ test methods that can be used to obtain geotechnical data. The most commonly used tests include the Standard Penetration Test (SPT), Cone Penetration Test (CPT), Dynamic Probe Super Heavy (DPSH), Plate Load Test (PLT), Field Vane Shear Test (FVST). Table 2.1 provides a summary of the measured parameters, advantages, disadvantages and level of performance in different types of materials/strata. The level of performance is simplified to only six types of materials and does thus not distinguish between different types of clays (soft, stiff etc.) and or mixed materials (gravelly-sand, sandy-silt etc.). The summary therefore intends to provide a quick way of seeing what type of tests may be appropriate for different types of material.

*Table 2.1: Most commonly used field tests.*

| Test | Parameters Measured | Clay | Silt | Sand | Gravel | Soft Rock | Hard Rock | Advantages | Disadvantages |
|---|---|---|---|---|---|---|---|---|---|
| **SPT** | Relative strength, relative density, consistency, stiffness, compressibility, friction | ✓ (Moderate) | ✓ (Moderate) | ✓ (High) | ✓ (High) | ✓ (Low) | × (Not Applicable) | Provides representative sample. Easy and economical. | Sample is disturbed. High variability and uncertainty. Test only performed in boreholes |
| **DCP** | Stiffness (density), in-situ strength | ✓ (Moderate) | ✓ (High) | ✓ (High) | × (Not Applicable) | × (Not Applicable) | × (Not Applicable) | Minimal surface disturbances, easy and cost-effective, identifies "soft spots" in strata. | Only measure stiffness, DCP can break in very stiff material. Typically, pavement applications. |
| **CPT CPTu** | Density, effective strength, permeability, Over-consolidation ratio, various moduli | ✓ (High) | ✓ (High) | ✓ (Moderate) | × (Not Applicable) | ✓ (Low) | × (Not Applicable) | Economical, fast and continuous profiling. Not operator-dependent. | Not applicable in hard and stiff clays or gravel. No sample obtained. Drainage conditions are not known. |
| **DPSH** | Effective angle of friction, relative density, shear strength compressibility | ✓ (Low) | ✓ (High) | ✓ (High) | ✓ (Low) | ✓ (Moderate) | ✓ (Low) | Cheaper than drilling boreholes. possible to reach necessary depth for investigations | Reliability of data of DPSH depends on the quantity of energy transferred to rods |
| **PLT** | Ultimate bearing capacity, settlement, Elastic modulus, | ✓ (Moderate) | ✓ (Moderate) | ✓ (Moderate) | ✓ (High) | ✓ (High) | ✓ (Moderate) | Applicable for most types of material, | Results exclude effects of consolidation, Slow and expensive, Limited depth, gives mostly immediate settlements |
| **FVST** | Undrained shear strength, Sensitivity (of clays) | ✓ (High) | ✓ (Moderate) | × (Not Applicable) | × (Not Applicable) | × (Not Applicable) | × (Not Applicable) | Easy and economical, Boreholes not always required, | Limited to soft to stiff clays and silts, Slow, time-consuming, needs empirical correction, affected by sand lenses. |

**High** **Moderate** **Low** **Not Applicable**

### 2.6.4 Laboratory Test Methods

Laboratory testing forms an essential part of the geotechnical investigation. Representative samples collected during the field investigation are used to perform various laboratory tests to obtain physical characteristics, index properties, strength and deformation parameters of soils and rocks. The type of laboratory tests depends on the nature and scope of the investigation. Disturbed samples are easier to collect but do not keep the in-situ properties of the material (soil or rock) and is therefore tested in the laboratory to obtain properties such as soil type, texture and moisture content that are not dependent on the composition and structure of the material. Samples that are relatively undisturbed retain the structural integrity and composition of in-situ soils and allow testing for properties such as permeability, strength and deformation parameters that depends on the structure and composition. It is however rather difficult to collect a perfectly undisturbed sample as there is always going to be some degree of disturbance when removing an in-situ sample of soil. Table 2.2 shows the parameters determined by some of the most commonly used laboratory tests.

*Table 2.2: Most commonly used laboratory tests (after Franki Africa, 2008).*

| **Parameters** | | **Laboratory Test** |
|---|---|---|
| Index Properties | Particle size distribution | Grading analysis |
| | | Atterberg Limits (PI, LL, SI) |
| | | Moisture content |
| Permeability | Permeability | Falling head permeameter (fine grained soils) |
| | | Constant head permeameter (coarse grained soils) |
| | | Rowe cell (fine and coarse-grained soils) |
| Physical characteristics | In-situ Density | Bulk Density Determination |
| | Specific Gravity | Specific Gravity test |
| | Moisture (water) Content | Moisture Content test |
| Strength Parameters | Undrained Shear Strength:<br>Unconfined compressive strength | Undrained triaxial test<br>UCS Test (rocks) |
| | Drained Shear strength:<br>Cohesion ($c$) and Friction angle ($\phi'$) | Shear box test<br>Drained triaxial test<br>Undrained triaxial with pore water pressure |
| Deformation Parameters | Consolidation | Consolidometer test<br>Rowe Cell test |
| | Compaction | Standard or Modified Proctor test |
| | Collapse | Double Oedometer<br>Collapsible potential test |
| | Heave | Double Oedometer<br>Swell under load test |

## 2.7 Phases of Investigation

Geotechnical site investigations are rarely straight forward and therefore often carried out in phases. The number of phases can vary and depends on the scope and objectives of the project. It is important that the original objectives of the investigation are satisfied during all the phases. Geotechnical investigations typically comprise a preliminary investigation, detailed investigation and investigation during construction. These phases are described below.

### 2.7.1 Preliminary Site Investigation (Phase I – Desk Study)

The preliminary Site Investigation (PSI) comprises a desk study a walk-over survey (visual inspection) of the site and surrounding areas carried out by a competent geotechnical practitioner. According to Clayton, Matthews and Simons (1995: 5), a desk study and site walk-over are the minimum requirement for satisfactory preliminary investigations.

The desk study includes but is not limited to a review of site historical records, a detailed study and analysis of topographical, geological, aerial maps and ortho-photographs. The investigator should also, if possible, assess previous geotechnical reports, newspaper reports, geotechnical and civil engineering journals to learn about possible geotechnical problems, gather information on services (water pipes, power lines etc.) and climatic data of the area. During the walk-over survey attention should be paid to physical state of existing buildings, presence of surface water, signs of contamination and indication of services on the site. It is also wise to talk to the current and/or previous owners or people who live close to the site to get more information about the site.

The purpose of PSI is to provide an initial conceptual site model. Information including the overall stability and suitability of the site in comparison with alternative sites, geotechnical limit states (bearing capacity, slope instability and settlement) that should be designed for, previous land use and existing services need to be reported on. The PSI should also establish preliminary nature of soil, rock and ground water to further determine and propose types of investigation methods (test pits, boreholes, in-situ tests, laboratory tests) to be applied during the detailed site investigation.

By understanding the potential variations in the ground, the likelihood of risk and unforeseen ground conditions and the use of inappropriate techniques in subsequent investigation phases may be reduced, therefore leading to economical investigation and minimizing chances of project delays.

### 2.7.2 Detailed Site Investigation (Phase II – Intrusive)

The requirements for the detailed (Phase II) site investigation and scope thereof usually depend on the results obtained and recommendations presented in the Preliminary (Phase I) investigation. The detailed investigation requires more in-depth exploration, sampling, collection and analysis of both surface and subsurface data. This phase of investigation typically relies on intrusive investigation methods such as test pitting and geotechnical drilling, in-situ testing and laboratory testing (see section 2.6.2) to collect and provide interpretive information to make recommendations regarding foundation and structural design. Investigation techniques and procedures chosen for the investigation usually depend on various factors identified during the PSI that includes the geology, site access, operational constraints and other potential risk factors.

Given the large amount of information that is gathered during the detailed investigation, it may be the costliest phase, and at the same time the most cost-effective phase of the investigation process as it reduces the potential for unforeseen ground conditions. It is therefore essential that geotechnical site investigations be carried out by and supervised by a competent qualified and experienced professional. Findings of the investigation should be presented in the form of a comprehensive and transparent report that may include, depending on the contractual agreement, recommendations for design and construction as outlined in section 2.5.4.

### 2.7.3 Investigation during Construction

The objectives of this phase of investigation is mainly to review and extend the findings of the previous phases of investigation. The investigation is usually done during earthworks, installation of services and foundation construction when larger parts of the subsurface is exposed, allowing the geology of the site to be assessed in a broader perspective. Additional testing may be undertaken if it is apparent that the ground conditions recorded during earlier phases of the investigation vary significantly across the site. In case of the latter, information obtained from trench inspections and additional testing may identify the need for further investigation to be conducted.

This type of information is crucial to any project at any stage, as it not only ensures safe and economical design but also tends to save clients a lot of money by identifying potential issues that was not picked up during earlier stages of the investigation. The necessity and importance of this part of the investigation is however often overlooked.

## 2.8 Cost of Investigations

The cost of a geotechnical site investigation depends on several factors which include but are not limited to access of the site, distance between anticipated data collection points, experience of the person conducting the investigation (engineering geologist or geotechnical engineer) as well as contractors (drillers, laboratory personnel), special contractors needed to do in-situ tests, quality and availability of equipment needed and Occupational Health and Safety. A direct link exists between the cost and quality of geotechnical investigations. Judging by the factors mentioned above, it can be concluded that the higher the quality and better the resources used in a site investigation, the better the results of it will be, therefore, possibly decreasing the risk associated with unforeseen ground conditions. However, the need to increase site investigation cost have been reported and called upon in numerous published and unpublished opinions (Williams and Mettam, 1971; Rowe, 1972; Clayton, Matthews and Simons, 1995) and yet, the need persists.

Clayton, Matthews and Simons (1995) reported that there has been a decline in financial provision made for geotechnical investigations for "fair-sized works" since the 1940's when expenditure on investigations was typically about 1% to 2% of the cost of the works. Table 2.3 shows the cost of site investigations as a percentage of the project cost for different types of work.

*Table 2.3: Site investigation costs (Rowe, 1972).*

| **Type of Work** | **% of capital cost of works** | **% of earthworks and foundation costs** |
|---|---|---|
| Bridges | 0,12 - 0,50 | 0,26 - 1,30 |
| Buildings | 0,05 - 0,22 | 0,50 - 2,00 |
| Docks | 0,23 - 0,50 | 0,42 - 1,67 |
| Earth dams | 0,89 - 3,30 | 1,14 - 5,20 |
| Embankments | 0,12 - 0,19 | 0,16 – 0.20 |
| Roads | 0,20 - 1,55 | 1,60 - 5,67 |
| Railways | 0,60 - 2,00 | 3,5 |
| **Overall mean** | **0,7** | **1,5** |

Figure 2.2 shows the financial risk related to inadequate site investigation costs from data obtained from a survey done on UK highway projects (Mott MacDonald & Soil Mechanics Ltd. 1994).

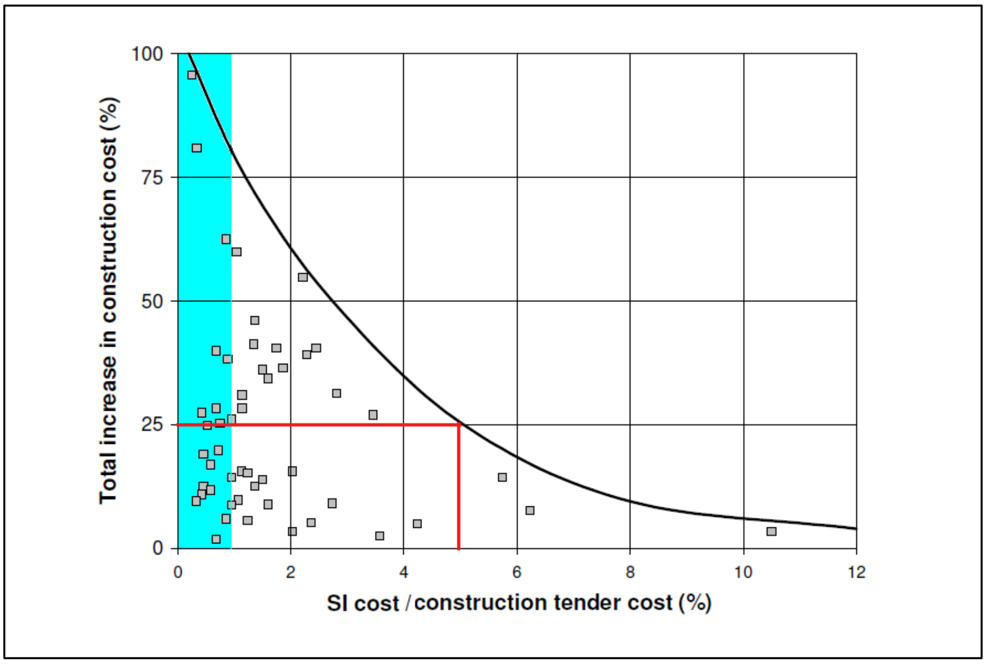



*Figure 2.2: The impact of expenditure on cost overruns for UK highway projects (Mott MacDonald & Soil Mechanics Ltd. 1994).*

There are two important observations that can be made from this graph.

- Expenditure of less than 1% exposes the client to up to 100% of cost over-run;
- When expenditure on ground investigation is 5% or more of the tender price, cost over-runs are typically less than 25% of tender price.

## 2.9 Conclusion

Since ancient times, many people have been devoted to practicing geotechnical engineering. The profession has come a long way and is now an established branch of civil engineering. The geotechnical site investigation intends to identify and characterise the ground conditions in sufficient detail to allow safe and economic design of structures. Although the risk inherent in the ground cannot be eliminated, the investigation aims to reduce the occurrence and impact of unforeseen ground conditions as far as possible.

Various approaches to conducting site investigations exists. It is important that the investigation proceed in a logical order of which desk studies and planning is usually the first step. There are numerous methods of investigating subsurface conditions and not all of these will be used in one site investigation. Proper planning is thus required to specify the most applicable investigation methods and field and laboratory tests required to adequately characterise ground conditions of a site.

Notwithstanding the fact that the geotechnical site investigation is nowadays widely considered as part of the contractual obligation, the importance of allowing adequate funding and time for investigation is still being overlooked and many parties including the client, designer, project manager and contractor fail who often fail to understand that, in the long term, it is their interests to do an adequate investigation.

# Chapter 3: The Regulatory Framework for Geo-Professionals in South Africa

"Perfection is achieved, not when there is nothing more to add, but when there is nothing left to take away."

- *Antoine de Saint-Exupery*

## 3.1 Introduction

The regulatory framework in South Africa contains legally binding requirements established by various Acts, Regulations as well as national standards and codes of practice which regulate the engineering and construction industries. In addition, the various professional councils (such as the Engineering Council of South Africa, the South African Council for Natural Scientific Professions and the South African Council for Project and Construction Management Professions) have codes of conduct which regulate professional conduct and ensure adherence to the norms of the profession. This chapter provides an overview of the regulatory framework that relates to the geotechnical environment by introducing the fundamental regulatory documents that contain sections relating to geotechnical investigations in South Africa. There are also numerous codes, standards and guidance documents that set specific requirements for geotechnical investigations for various types of development. These requirements are discussed in detail in Chapter 4.

Information in this chapter was mostly derived from the lecture on Codes and Standards presented by Professor Peter Day to the SAICE Geotechnical Division (Day, 2016) and an Advisory Note for the public by the Engineering Council of South Africa (ECSA, 2012), also available from their website (www.ecsa.co.za).

## 3.2 Legislative Requirements for Geotechnical Investigations

There are three main Acts that set out requirements that specifically apply to geotechnical investigations in South Africa.

### 3.2.1 National Building Regulation and Building Standards Act

The National Building Regulations and Building Standards Act (No. 103 of 1977) including the National Building Regulations (or NRBs) provide requirements to ensure that all buildings in South Africa are designed and constructed such that people can live and work in a safe and healthy environment (Foreword to SANS10400A:2010). The introduction to the Act states the purpose of the act to be "to provide for the promotion of uniformity in the law relating to the erection of buildings in the areas of jurisdiction of local authorities; for the prescribing of building standards; and for matters connected therewith". The Act itself deals mainly with administrative procedures. The functional requirements for buildings are set out in the National Building Regulations. The means whereby these functional requirements are to be satisfied are set out in SANS 10400 – The application of the National Building Regulations. The methods of compliance include "deemed-to-satisfy" provisions (SANS 10400 Parts C – X) and rational design (SANS 10400 Part B). These parts of SANS 10400 correspond to the various parts of the National Building Regulations.

Regulations A19 requires any person applying for permission to erect a building to appoint a competent person by means of an A19 form (Form 2, SANS 10400-A:2010), to undertake a geotechnical investigation in terms of Regulation F3, when the applicant and or local authorities have reason to believe that the site is situated on contaminated land and problem soils are present. Regulation F3 further states that geotechnical investigations will be deemed appropriate is conducted in accordance with the requirements of SANS 10400-B:2012 in the case of dolomite land and SANS 10400-H:2012 for foundations. Sections 1 and 2 of the A19 form clearly set out the responsibilities of the owner and the competent person respectively. The Act also states that when the competent person fails to fulfil their duties, the owner/applicant must appoint another competent person to take responsibility and fulfil remaining duties to complete the project.

### 3.2.2 Housing Consumers Protection Measures Act

The Housing Consumers Protection Measures Act (95 of 1998) provides protection for housing consumers. The Act also established the National Home Builders Registration Council (NHBRC) as a regulatory body of the home building industry. The NHBRC protects housing consumers by requiring all home builders to be enrolled with them so as to be covered by their warranty scheme. The warranty provides protection and assistance against major structural defects caused by substandard design, bad quality building materials or poor workmanship.

The Home Building Manual published by the NHBRC (NHBRC, 2015) requires that site specific geotechnical investigations be undertaken by a listed competent person. For the development of dolomite land, the NHBRC requires compliance with SANS 1936 and, for establishment of new townships, compliance with SANS 634:2012 is required. As part of the enrolment process, the Competent Person must provide a soil classification of the site relating to the nature and severity of any anticipated geotechnical problems on the site.

### 3.2.3 Occupational Health and Safety Act

There are numerous hazards and risks associated with construction work. These are regulated by the Occupational Health and Safety Act (95 of 1998) and the Construction Regulations promulgated under the act. The Regulations aim to create a safe working environment for all parties involved in the construction of any structure, and also provide protection to people that are indirectly involved in terms of hazards to health and safety arising out of or in connection with the activities of persons at work. The Regulations set out the role and responsibilities of the various parties involved in construction work. In terms of these Regulations:

- The Client must ensure that the designer's work is in accordance with the health and safety specifications (Regulation 5(1)).
- The Designer is required to provide the client with a report on the "geotechnical-science" aspects where appropriate and inform the client of any known or anticipated hazards related to the construction work (Regulation 6(1)).
- Regulation 13 sets out requirements for the assessment of the stability of excavations and of surrounding structures and services. It also requires all excavations be carried out under the supervision of a competent person.

## 3.3 Codes and Standards

Codes and standards are widely used in the engineering field. They aim to establish norms within the profession and provide standard requirements for engineering projects. Codes and standards fall into two categories namely industry standards published by the profession and national standards published by the South African Bureau of Standards (SABS). In South Africa, codes and standards are not mandatory unless referenced in legislation or required by contract. They are generally regarded as a statement of acceptable practice.

This section gives a short description of some of the codes and standards that are applicable to geotechnical investigations.

### 3.3.1 SAICE Code of Practice for Site Investigations

The SAICE Site Investigation Code of Practice (SAICE, 2010) is an industry standard written by the Geotechnical Division of the South African Institution of Civil Engineering (SAICE). It serves as a guide to the South African civil engineering industry and provides recommendations on a systematic way of carrying out site investigations for various types of projects. The document intends to assist all parties involved in engineering projects (clients, consultants, contractors etc.), in understanding all the aspects of site investigation. It is divided into six parts and covers the planning, procurement, execution, reporting and verification during construction.

### 3.3.2 The Application of the National Building Regulations

SANS 10400: The Application of the National Building Regulations establishes general requirements and deemed-to-satisfy provisions for satisfying the National Building Regulations by providing various possible ways of demonstrating compliance with functional regulations. The standard is divided into various sections each of which corresponds with the respective parts of the National Building Regulations. A geotechnical investigation is defined in SANS 10400 Part A: *General Principles and Requirements*, Part B: *Structural Design* and Part H: *Foundations* as the process of evaluating the geotechnical character of the site in the context of existing or proposed land usage.

### 3.3.3 Investigations for Houses, Townships and Developments on Dolomite Land

Investigation requirements for housing development, township development and on dolomite land is set out in the following standards:

- Generic Specification GFSH-2:2002 Geotechnical site investigations for housing developments (largely superseded by SANS 634:2012)
- SANS 634:2012 Geotechnical investigations for township development
- SANS 1936-2:2012 Development of dolomite land – Geotechnical investigations and determinations

These standards set out a phased approach to geotechnical investigations including preliminary assessment of site conditions, detailed investigation and further investigation during construction. Local authorities and the NHBRC generally require adherence to these standards as a condition of approval of any development.

### 3.3.4 Design Standards

SANS 10160: Basis for Structural Design and Actions for Buildings and Industrial Structures consists of eight parts that forms part of the design standards used in South Africa. The standard focus on providing the basis for structural design in terms of design procedures to be applied, actions to be considered and associated levels of reliability amongst other factors.

SANS 10160-5:2010 *Basis for geotechnical design and actions* forms part of SANS 10160:2011 *Basis for structural design and actions for building and industrial structures*. Although the focus is primarily to set out the basis for geotechnical design, Clause 6 sets out requirements for the geotechnical investigation and refers to Annex A (as part of the document) which defines four geotechnical categories of structures ranging from straightforward to very complex. Category 4 is not covered in the table provided in the standard but some of the aspects are described in the text. Table

3.1 (after Day, 2015) provides a summary of the basic requirements for structures falling into each of these categories.

*Table 3.1: General requirements for various geotechnical categories (after Day, 2015).*

| State and Actions Required | Geotechnical Categories | | | |
|---|---|---|---|---|
| | Category 1 | Category 2 | Category 3 | Category 4 |
| **Ground Conditions** | Relatively straightforward (above water table) | Not Problematic | Complex | Very Complex / Unstable |
| **Structure** | small and relatively simple | Conventional Design | Complex Design | Very Large or Unusual (lie outside of category 1-3) |
| **Risk** | Negligible | Low | Moderate (Not Exceptional) | High (Abnormal) |
| **Geotechnical Investigation** | Qualitative | Quantitative | Specialised | Specialised |
| **Supervision** | Routine inspections | Systematic inspections | Detailed inspections | Additional or alternative rules required. |
| **Monitoring** | Monitoring only reactive | Monitoring only if appropriate | Planned Monitoring programme | Additional or alternative rules required. |

Table 3.2 is an extract from Table A.1 in SANS 10160-5 which sets out the geotechnical investigation requirements in more detail.

*Table 3.2: Geotechnical requirements for each category (Table A.1, SANS 10160-5:2010).*

| Activity | Category 1 | Category 2 | Category 3 |
|---|---|---|---|
| **Geotechnical investigation** | Qualitative geotechnical investigations including a systematic description of the soil profile and groundwater conditions and identification of problem soils<br><br>May be supplemented by basic field and laboratory tests | As in category 1, supplemented by routine field and laboratory tests producing quantitative geotechnical data for design purposes | As in category 2 but including specialised field and laboratory tests as specified by the geotechnical engineer |

SANS 10161:1980 *Design of foundations for buildings* aims to ensure that design for building foundations are carried out in a systematic manner by setting out the minimum requirements for the design of building foundations. Clause 3 of the standard deals with site investigation and inspections, documents and approval. The standard places the responsibility on the designer to ensure that a site investigation is carried out prior to the commencement of any design work (clause 3.1). It also set requirements for a detailed site investigation (clause 3.1.2) and confirmation of site conditions (clause 3.1.3). SANS 10161 pronounces on the responsibility of individual parties, which is considered overstepping the line between a standard and a contract document and is therefore being considered for withdrawal by the SA Bureau of Standards (Day and Kirsten, n.d.).

## 3.4 Professional Conduct, Statutory and ethical Obligations

Any engineering project comprises principal role players that include clients, consultants, contractors and sub-contractors each of whom have certain responsibilities in terms of legislation. In general practice and in terms of the norms of the profession, geotechnical engineers and engineering geologists assume a series of generic responsibilities that relate to the scope of their work. It is required by most of the national standards and codes of practice that the geotechnical investigation be conducted by a competent person i.e. a geotechnical engineer or engineering geologist that is registered as a professional.

Professional registration provides confirmation and recognition of the qualifications, knowledge, experience, competence and commitment to maintaining professional standards. Engineers, including geotechnical engineers, are registered with Engineering Council of South Africa (ECSA) while engineering geologists are registered with the South African Council for Natural Scientific Professions (SACNASP).

Professionals are bound to abide by the codes of conduct set out by these organisations (See Appendix A1 and A2 for the ECSA code of conduct and the SACNASP code of conduct respectively). The rules of conduct for professional engineers require registered professionals to adhere to the norms of the profession. These codes regulate the conduct of registered professional and failure to comply constitutes improper conduct for which professionals may be disciplined. Extracts from the ECSA and SACNASP Codes as well as the ECSA Guideline Scope of Services and Tariff of Fees that highlight the responsibilities of geo-professions are given below:

<u>ECSA Code of Conduct (2013):</u>

The ECSA Code of Conduct states in Clause 3(1) that persons registered with ECSA:

(a) must discharge their duties to their employers, clients, associates and the public effectively with skill, efficiency, professionalism, knowledge, competence, due care and diligence.
(b) …..
(c) must when carrying out work, engage in and adhere to acceptable practices.

<u>SACNASP Code of Conduct:</u>

The Code of Conduct for Natural Scientists states that Registered Persons must:

(3) discharge their duties to their respective employers or clients efficiently and with integrity.

ECSA Guideline Scope of Services and Tariff of Fees

Clause 3 (1) of the Guideline published in …… sets out the services normally provided by the engineer:

(1) Consultation with the client or client's authorized representative.
(2) Inspection of the site of the project
(3) Preliminary investigation, route location, planning and a level of design appropriate to allow decisions on feasibility.
(4) Consultation with authorities having rights or powers of sanction as well as consultation with the public and stakeholder groups.
(5) Advice to the client as to regulatory and statutory requirements, including environmental management and the need for surveys, analyses, tests and site or other investigations, as well as approvals, where such are required for the completion of the report, and arranging for these to be carried out at the client's expense.
(6) Searching for, obtaining, investigating and collating available data, drawings and plans relating to the works.

Note that the numbering of this specific clause in the ECSA Guideline Scope of Services and Tariff of Fees is different in versions of the document issued after 2006. Where the clause is referred to, the latest version at the time of the incident would have been applicable.

## 3.5 Standard forms of Contracts used in the Engineering Industry

Like any other contract, engineering and construction contracts create legally enforceable obligations for all the role players involved in a construction project. Although ad hoc oral or written agreements can also be used, professionals are typically appointed using industry standard agreements. The most common standard forms of agreement for the appointment of registered persons providing professional services includes the following (ECSA, 2012):

i. PROCSA – Client / Consultant Professional Services Agreement

ii. The Short Form of Agreement for Consulting Engineering Services

iii. FIDIC – Client / Consultant Model Services Agreement

iv. NEC – Professional Services Contract

v. CIDB – Standard Professional Services Contract

Other forms of agreement that are commonly used in the construction industry are listed below. These agreements do not necessarily focus on professional services.

i. GCC – General Conditions of Contract for Construction

ii. JBCC – Principal Building Agreement and Minor Works Agreement

## 3.6 Dissatisfaction with Professional Services

A registered professional who provide a professional service involving specialised knowledge or expertise can be held liable for their actions and be held responsible for payment of damages arising from a breach of their professional duties. In the engineering and construction industry, these professionals include geo-professionals, designers, contractors, project managers or construction managers. Geo-professionals who fail to adequately conduct geotechnical site investigations may be faced with three types of professional liability discussed below.

### 3.6.1 Professional Misconduct

Registered persons must adhere to a code of conduct established by the relevant Professions Act. These codes typically require adherence to the norms of the profession and the exercise of skill, care and diligence in the execution of their professional duties. Failure to adhere to these requirements may result in a disciplinary hearing. If found guilty, the professional may face various sanctions such as having to pay a fine, receiving a warning or having their professional registration temporally suspended or cancelled.

### 3.6.2 Civil Liability

Civil liability typically arises from claims by the client and/or a third party (members of the public) for damage suffered as a result of a breach of contractual obligations or negligence. Third party claims, where no contract exists between the parties, are governed by the laws of delict. Most professionals include appropriate clauses in the contract agreement placing a limit on the compensation payable in the event of a contractual claim.

### 3.6.3 Criminal Liability

Criminal liability usually arises from violation of statutory duties established by an Act or Regulations associated with an Act. The most common occurrences of criminal liability arise from contraventions of the Occupational Health and Safety (OHS) Act, particularly where these result in loss of life or injury. In case of assessing construction accidents and fatalities, it needs to be established whether the cause originated from failure to comply with OHS regulations. This type of investigation is usually done by the Department of Labour. Where there is evidence of contravention of the Act, for example the death of a worker due to collapse of a trench, the matter is handed over to the Public Prosecutor. If found guilty of an offence, the professional may be required to pay a fine or could face imprisonment.

## 3.7 Determination of Professional Liability

The assessment of professional liability is based largely on whether the professional acted with skill, care and diligence in accordance with the norms of the profession or whether there was a breach of contractual requirements.

The norms of the profession are set out in standards, codes of practice and codes of conduct. The ECSA code of conduct relates to competency, integrity, public interest, environment and dignity of the profession (ECSA, 2012). Contractual requirements are established by professional services agreements such as the NEC Professional Service Contract of the FIDIC Client-Consultant Agreement. The former requires the professional to use the skill and care normally used by professionals whereas the latter requires the exercise reasonable skill, care and diligence.

Day and Kirsten (n.d.) stated that the norms of the profession are established (roughly in order of increasing importance) by:

- standard forms of agreement where no formal contract exists,
- scope of services and schedules of tariffs as published by the professional councils,
- relevant requirements of codes and standards,
- rules of professional conduct, and
- expert testimony.

It is therefore irrelevant whether a particular code or standard is mandatory or voluntary. Where such codes represent accepted norms, they will be used in the assessment of professional liability whether mandatory or not.

## 3.8 Professional Indemnity Insurance

Uncertainty within the ground is one of the most common reasons why geo-professionals will always be exposed to risk. A simple error of judgement or omission is all it takes to trigger a claim, especially with clients and third parties becoming increasingly aware of their rights to hold professionals accountable for their losses. Where such claims arise, it may be covered by professional indemnity (PI) insurance. PI insurance provides protection to professionals in the event of a claim made as a result a breach of their professional obligations. The protection includes legal and other costs. It is however important to note that neither professional misconduct nor criminal liability are covered by professional indemnity insurance, and there is no limit of liability in a delictual claim. Claims made as a result of breach of contract involve the principles of contract law and are typically resolved in accordance with the dispute resolution provisions of the contract.

## 3.9 Conclusion

There is, without a doubt, a lot of risk associated with work relating to geoscience, engineering and construction. The importance of having a coordinated framework that regulates the responsibilities of different role players cannot be overemphasized. With respect to geotechnical work, the responsibility mainly rests upon registered professionals to promote the quality of the profession. The fact that construction incidents and foundation failures still occur on a regular basis suggests that the profession is not fully aware of these requirements or the importance of complying with these requirements. It is therefore recommended that these rules be consulted at an early stage of a project, for example as part of the planning phase, before starting an investigation to make sure all involved parties know exactly what is legally expected from them.

# Chapter 4: Specific requirements for various categories of development

"Truth has nothing to do with the conclusion, and everything to do with the methodology."

\- *Stefan Molyneux*

## 4.1 Introduction

In addition to legally binding documents (Acts, Regulations and Contractual Agreements) that enforce compliance of minimum requirements for site investigations, various standards and codes of practice set out investigation requirements for different types of development. This chapter summarises the minimum investigation requirements that specifically apply to particular types of developments. These are township development, housing development, and development on dolomite land, investigations for piled foundations, excavations and lateral support and investigations for linear structures. The minimum geotechnical investigation requirements extracted from the codes and standards that are most relevant to a particular type of development are grouped together for ease of reference.

## 4.2 Geotechnical Investigations for Township Development

### 4.2.1 Applicable Standards

The standards that are most relevant to township development are:

- SANS 634:2012 Geotechnical investigations for township development,
- SANS 10400-H:2012 The application of the National Building Regulations - Part H: Foundations, and
- SAICE (2010) Site investigation Code of Practice.

Standards applicable to dolomite land are dealt with in section 4.4.

### 4.2.2 Objectives of Investigation

The main objectives of the three-phased investigation approach advocated in SANS 634:2012 for township investigations are to establish whether a parcel of land is suitable for township development (Clause 4.2.1); to determine the foundation characteristics of the near-surface horizons (Clause 4.3.1); and to confirm the site class designations during installation of services (Clause 4.4.1).

### 4.2.3 Specific Requirements

SANS 634:2012 requires the investigation to be carried out by a competent person who has suitable experience in geotechnical site investigations and is registered as a Professional Engineer, Professional Engineering Technologist or a Professional Natural Scientist. This is one of the few codes that requires professional registration of the competent person. This probably reflects the view that it is better and more cost effective to recognise and adequately investigate geotechnical constraints at township proclamation stage than to expect individual home builders to deal with these on a stand-by-stand basis.

Three phases of investigation are required, namely a Preliminary Investigation, a Phase 1 Detailed Investigation and a Phase 2 Detailed Investigation.

<u>The Preliminary Investigation</u> (clause 4.2) requires a desk study and a site walk-over, possibly with limited fieldwork such as test-pitting. Its aim is to identify geotechnical constraints which are then categorised into three classes namely, (1) most favourable, (2) intermediate and (3) least favourable. These constraints are:

A. Collapsible soils – soils which settle due to wetting
B. Seepage – presence of shallow ground water
C. Active soils – soils which shrink and swell with changes in moisture content
D. Highly compressible soils – soils that settle under load
E. Erodible soils – includes dispersive soils
F. Difficulty of excavation above 1,5m depth
G. Undermined ground – assessed in terms of depth and age of mining
H. Stability of dolomite land – dealt with in section on dolomites
I. Slope of land – surface gradient
J. Unstable natural slopes – risk of slope instability or landslides
K. Seismic activity – deals with natural and mining induced seismic activity
L. Risk of flooding – proximity to drainage channels and flood lines.

Requirements are also laid down for the contents of the report on the Preliminary Investigation (clause 4.2.6).

The <u>Phase 1 Detailed Investigation</u> (clause 4.3) deals with the stability of the land (e.g. dolomite subsidence, undermining and slopes) and the founding characteristics of the near surface soil horizons. Amongst the requirements for this phase of the investigation (clause 4.3.1) are:

- Definition of ground conditions within the zone of influence of foundations,

- Broad classification of the land in terms of site class designations as defined in SANS 10400-H:2012 (see below), and
- Factual data relating to the construction of houses and installation of services.

Table 3 of SANS 634:2012 specifies the minimum frequency of test pits which ranges from 4 pits per hectare for small areas to 0.3 pits per hectare for large areas. The minimum number of laboratory tests (foundation indicator, consolidometer and chemical tests) to be carried out is specified in Table 4, and the method of classifying the excavatibility of material is given in Table 5 of SANS 634:2012.

As with the Preliminary Investigation, the format and contents of the report are specified in clause 4.3.2.4).

The Phase 2 Detailed Investigation requires the inspection of trenches during installation of services to confirm the findings of the Phase 1 investigation and confirm / refine the site class designations for individual stands in the township in accordance with Table 1 of SANS 10400-H:2012, as given in Table 4.1 below.

*Table 4.1: Site class designations for Township development from Table 1 of SANS 10400-H.*

| **Typical founding material** | **Nature of founding material** | **Expected range of total soil movements** mm | **Assumed differential movement** % of total | **Site class designation** |
|---|---|---|---|---|
| Rock (excluding mud rocks which might exhibit swelling to some depth) | Stable | Negligible | – | R |
| Fine-grained soils with moderate to very high plasticity (clays, silty clays, clayey silts and sandy clays) | Expansive soils | < 7,5<br>7,5 to 15<br>15 to 30<br>> 30 | 50<br>50<br>50<br>50 | H<br>H1<br>H2<br>H3 |
| Silty sands, clayey sands, sands, sandy and gravelly soils | Compressible and potentially collapsible soils | < 5<br>5 to 10<br>> 10 | 75<br>75<br>75 | C<br>C1<br>C2 |
| Fine-grained soils (clayey silts and clayey sands of low plasticity), sands, sandy and gravelly soils | Compressible soils | < 10<br>10 to 20<br>> 20 | 50<br>50<br>50 | S<br>S1<br>S2 |
| Contaminated soils, controlled fill, dolomite land, landslip, landfill, marshy areas, mine waste fill, mining subsidence reclaimed areas, uncontrolled fill, very soft silts/silty clays | Variable | Variable | – | P |

The SAICE Site Investigation Code of Practice (SAICE, 2010) deals in greater detail with various methods of investigation for all types of development. It advocates a similar three-phase approach namely preliminary investigation, detailed investigation and investigation during construction.

## 4.3 Geotechnical Investigations for Houses

### 4.3.1 Applicable Standards

The standards most relevant to housing development are:

- NHBRC (2015) Home Building Manual,
- SANS 10400-H:2012 The application of the National Building Regulations - Part H: Foundations, and
- SAICE (2010) Site investigation code of practice.

### 4.3.2 Objectives of Investigation

The objectives of the investigation are to classify the founding conditions on the site (typically a stand for an individual house or cluster of houses) to enable the appropriate selection and design of the foundations in order to limit damage to the building to acceptable levels.

### 4.3.3 Specific Requirements

The NHBRC Home Building Manual (NHBRC, 2015) lays down requirements for the construction of homes, including all types of residential development. Unlike the earlier version of the Home Building Manual, the 2015 version does not provide detailed requirements but refers instead to the relevant SABS standards including SANS 10400-H:2012.

Geotechnical investigations are to be carried out by a listed competent person or an approved certification body, registered with the NHBRC.

Part 2 of the manual specifies performance requirements for houses. In particular, damage to houses is to be limited to Category 1 damage (very slight) in terms of damage categories defined for walls, concrete surface beds and floors in Tables 5 to 7 of the NHBRC (2015) Home Building Manual.

Part 4 of the Manual requires classification of residential sites on a stand-for-stand basis in accordance with the site class designations given in Table 4.1, as per Table 1 of SANS 10400-H:2012.

Housing on dolomite land is dealt with in Parts 5 and 13. The requirements of SANS 1936:2012 Development on dolomite land apply, but are modified in certain respects including:

- A change to the definition of a competent person given in SANS 1936:2012,
- Changes to the classification of residential structures, and
- Prohibition of all housing development on areas where there is a medium or high risk of very large sinkholes and high-density development on areas with a high risk of large sinkholes (Tables 5.5 ad 5.6 of the guide to the Manual).

Part 6 of the Manual deals with Greenfield site development, i.e. new townships. It relies on the requirements of SANS 643:2012 as discussed above. Certain modifications given in Part 12 of the Manual in respect of dolomite land and the definition of a competent person, both as indicated above.

## 4.4 Geotechnical Investigations on Dolomite Land

### 4.4.1 Applicable Standards

The standards most relevant to development on dolomite land are:

- SANS 1936-2:2012 Development of dolomite land (Geotechnical investigations and determinations) in conjunction with SANS 1936-1:2012 (General principals and requirements),
- NHBRC (2015) Home Building Manual, and
- SANS 633:2012 Soil profiling and percussion borehole logging on dolomite land in Southern Africa for engineering purposes.

### 4.4.2 Objectives of Investigation

The objective of geotechnical investigations as given in SANS 1936-2:2012 is to set requirements for the development of dolomite land mainly by providing the information needed for identification and quantification of hazards (clause 4.1.1 a); determination of inherent hazard classes (IHC) of the site (clause 4.1.1 b); and determination of dolomite area designations which dictate the precautional measures required in development on such land (clause 4.1.1 c). These requirements are intended to ensure a safe environment, tolerable hazard and sustainable land usage.

### 4.4.3 Specific Requirements

SANS 1936-2:2012 requires three phases of investigation namely Feasibility-level geotechnical investigations, Design-level investigations and Investigations during installation of services.

All the phases of geotechnical investigations are required to be carried out by a competent person i.e. a geo-professional who is qualified by virtue of experience, qualifications, training and in-depth contextual knowledge of development on dolomite land.

The Feasibility-level investigations (clause 4.2) requires a gravity survey, borehole drilling, near-surface investigations (test pits and exploratory trenches) and geo-hydrological investigations (level of ground water and original water table level). Table 1 of SANS 1936-2:2012 specifies the minimum frequency of boreholes in dolomite areas which ranges from 3 holes per hectare for small areas to 0.15 holes per hectare for large areas.

It is required that the site be broadly delineated into inherent hazard zones which are considered suitable or unsuitable for development and that determination of inherent hazard classes (IHC) be done in accordance with Tables 2, 3 and 4 of SANS 1936-2:2012. Table 2 of SANS 1936:2012 describes the likely size of sinkholes as small, medium, large and very large (refer to Table 4.2 below).

*Table 4.2: Description of sinkhole sizes, as per Table 2 of SANS 1936-2:2012.*

| **Maximum diameter of surface manifestation** (m) | **Descriptor** |
|---|---|
| < 2 | Small sinkhole |
| 2 to 5 | Medium-size sinkhole |
| 5 to 15 | Large sinkhole |
| > 15 | Very large sinkhole |

Table 3 of SANS 1936-2:2012 specifies the inherent hazard in three categories (low, medium and high) in terms of the number of events per hectares per 20 years, as given in Table 4.3.

*Table 4.3: Inherent hazard categories, as per Table 3 from SANS 1936-2:2012.*

| **Inherent hazard category** | **Anticipated events per hectare per 20 years** |
|---|---|
| Low | Less than 0.1 events, but occurrence of events cannot be excluded. Return period of an event occurring in an area of 1 ha is greater than 200 years. |
| Medium | Between 0.1 and 1.0 events. Return period of an event occurring in an area of 1 ha is between 200 and 20 years. |
| High | Greater than 1.0 events. Return period of an event occurring in an area of 1 ha is less than 20 years. |

After the sinkhole size and inherent hazard has been determined, the site is characterised in terms of eight standard inherent hazard classes (IHC) as given in Table 4.4. These classes indicate the chance of a sinkhole occurring as well as its likely size (diameter). The potential damage to development increase with an increase in the inherent hazard class number.

*Table 4.4: Inherent hazard classification, as per Table 4 from SANS 1936-2:2012.*

| **Inherent hazard class** | **Statistical occurrences of sinkholes and subsidences** | | | | |
|---|---|---|---|---|---|
| | **Small sinkhole** | **Medium sinkhole** | **Large sinkhole** | **Very large sinkhole** | **Subsidence** |
| | **< 2 m** | **2 m to 5 m** | **5 m to 15 m** | **> 15 m** | |
| Class 1 | Low | Low | Low | Low | Low |
| Class 2 | Medium | Low | Low | Low | Medium |
| Class 3 | Medium | Medium | Low | Low | Medium |
| Class 4 | Medium | Medium | Medium | Low | Medium |
| Class 5 | High | Low | Low | Low | High |
| Class 6 | High | High | Low | Low | High |
| Class 7 | High | High | High | Low | High |
| Class 8 | High | High | High | High | High |
| NOTE The statistical occurrence of the event/hectare over a 20-year period is in the following ranges:<br>– low: 0 < 0,1 (return period is greater than 200 years)<br>– medium: > 0,1 < 1,0 (return period is between 200 and 20 years)<br>– high: > 1,0 (return period is less than 20 years) | | | | | |

The inherent hazard classes and the intended land use are used in conjunction with the requirements specified in SANS 1936-1:2012 to determine the dolomite area designation of the site, D1 – D4, using Table 2 of SANS 1936-1. The dolomite area designation determines the precautionary measures required to support development as reflected in Table 1 of SANS 1936-1 as reproduced below.

*Table 4.5: Dolomite area designations, as per Table 1 from SANS 1936-1:2012*

| **Dolomite area designation** | **Description** |
|---|---|
| D1 | No precautionary measures are required. |
| D2 | General precautionary measures, in accordance with the requirements of SANS 1936-3, that are intended to prevent the concentrated ingress of water into the ground, are required. |
| D3 | Precautionary measures in addition to those pertaining to the prevention of concentrated ingress of water into the ground, in accordance with the relevant requirements of SANS 1936-3, are required. |
| D4 | Additional site-specific precautionary measures are required. |

The Design-level Investigations (clause 4.3) are carried out when there is a need for additional information or confirmation of the findings of the feasibility-level investigation. Amongst the requirements for this phase of the investigation (clause 4.3.2) are:

- Investigations for specific types of development in accordance with the requirements of annex A (see below), and
- Footprint investigations to confirm, refine or amend the inherent hazard class below the footprint of the structure and the associated dolomite area designations.

The format and contents of the report on the Feasibility-level investigations is specified (clause 4.2.6). These reporting requirements also apply to the Design-level investigation.

Annex A of SANS 1936-2:2012 sets additional requirements for specific types of development including:

- Township developments
- Infill development on residential stands
- Rezoning and multiple dwelling rights on residential stands
- Major roads, railway lines and runways
- Bulk pipelines
- Pump stations and water care works
- Attenuation dams, retention dams, reservoirs and public swimming pools

Parts 5 and 13 of the NHBRC Home Building Manual require compliance with SANS 1936:2012 for housing on dolomite land, but modifies these requirements in certain respects as discussed in section 4.3.3 above.

SANS 633: 2012 (Soil profiling and percussion borehole logging on dolomite) land lays down the methods, procedures and nomenclature required to accurately describe the ground profile in dolomite areas. Additional soil profiling requirements on dolomite land (clause 4.2.4) include among other that any features that could influence inherent hazard classification of the profile in terms of SANS 1936:2012 to be noted.

All soil profiling and percussion borehole logging on dolomite land must be done in accordance with SANS 633:2012.

## 4.5 Geotechnical Investigations for Pile Foundations

### 4.5.1 Applicable Standards

Although there is currently no formal document that focuses specifically on investigations for pile foundations in South Africa, the documents most relevant to investigations for pile foundations are:

- A guide to practical geotechnical engineering in Southern Africa (Franki Africa, 2008) (referred to as the “Frankipile book”),

- SAICE (2010) Site investigation code of practice, and
- SANS 10160:2010 Basis of structural design and actions for buildings and industrial structures – Part 5: Basis for geotechnical design and actions

### 4.5.2 Objectives of Investigation

The main objective for geotechnical investigations for pile foundations are to provide the geotechnical information required by the designer for selection of pile types the design of piles and information required by the contractor for determination of construction methods to be used and pricing of the work. The design of piles requires quantitative information on the shear strength and the compressibility of the surrounding ground and the depth of the water table.

### 4.5.3 Specific Requirements

Section 2.4 of the "Frankipile book" (Franki Africa, 2008) specifies the minimum site investigation requirements for piling to include:

- Establishment of competent founding material and engineering properties thereof,
- Presence or absence of obstructions, including depth of fill or builders' rubble,
- Presence of water/seepage and the risk of hole collapse or the necessity of casing over all, or part of the hole depth,
- Presence of cavities,
- Presence of aggressive soil/water, and
- Consistency of the soil profile, including penetrometer data.

The SAICE Site Investigation Code of Practice (clause 2.8) requires the depth to which the investigation for piles (deep foundations) be carried out as:

- **Pile length + foundation width** (to the width of the pile group below the founding depth of the group) for pile groups in soils,
- **Pile length + 5.0 m** (to at least 5m into bedrock with a consistency of soft rock or better) for pile groups bearing on rock, and
- **Pile length + 3 x pile base diameter** (three diameters below the pile tip) for individual piles.

The same requirements are specified in the "Eurocode" BS EN 1997-2:2007 Ground Investigation and Testing (clause B.3).

The SAICE Code also requires the investigator to extend borehole depths if they cannot confidently tell that investigations are stopped in a competent horizon, i.e. one which is not underlain by incompetent bedrock or soft soils.

In SANS 10160-5:2011, Annex A classifies geotechnical works into four categories (see Table 3.1). Investigation for pile foundations to fall into Category 2 and are therefore required to provide quantitative geotechnical data for use in design of the piles and pile groups (clause A.2.2).

## 4.6 Geotechnical Investigations - Excavations and Lateral Support

### 4.6.1 Applicable Standards

The standards most relevant to investigations for excavations and lateral support are:

- SAICE (1989) Lateral Support in Surface Excavations code of practice (SAICE, 1989),
- SAICE (2010) Site investigation code of practice (SAICE, 2010),
- A guide to practical geotechnical engineering in Southern Africa (Franki Afrcia, 2008),
- SANS 10160-5:2011 Basis for geotechnical design and actions,
- SANS 634:2012 Geotechnical investigations for township development, and
- SABS 1200D:1988 Earthworks.

### 4.6.2 Objectives of Investigation

Investigations for excavations and lateral support aim to provide the geotechnical information required for assessment of excavatibility of materials, safe side slopes, selection of methods of support and quantitative information for design of any lateral support or shoring systems.

### 4.6.3 Specific Requirements

Clause 2.2 of the Lateral Support Code (SAICE, 1989) requires investigations for excavations and lateral support to provide the information required to assess the overall stability of the proposed work, the most appropriate support system both temporary and permanent, the magnitude of expected ground movements, the influence of groundwater, and the effect (potential damage) on adjacent development. Further requirements set out in clause 2.4 are:

- Extent of investigation to include the surrounding retained material and the material below the base of the excavation.
- Lateral extend of a distance twice the depth of the excavation beyond the excavation perimeter (excavation depth x 2).
- Vertical extend to a stable geological formation, or to a depth below which no underlying strata will affect the design (typically, excavation depth + excavation width).
- Investigation to continue 3 m into rock.
- A minimum of 3 holes for minor excavations on small sites.

- A minimum of 5 holes for a uniform site of 1000 $m^2$.
- A minimum of 9 holes for a uniform site of 4000 $m^2$.
- 1.5 m vertical spacing between undisturbed samples and 0.75 m spacing between disturbed samples.

Clause 4.3.3 of the Site investigation code (SAICE, 2010) deals with monitoring during construction, active design (using the Observational Method) and further investigations during construction, both of which are particularly relevant to lateral support works.

Section 2.5 of the Frankipile book (Franki Africa, 2008) lays down the minimum requirements for site investigations for lateral support projects as:

- Establishment of shear strength parameters of the material in front of, and behind the wall.
- Establishment of the soil stiffness in front of, and behind the wall (penetrometer data is a minimum requirement).
- Presence of water table / seepage.
- Likelihood of anchor/nail hole collapse (casing requirement).
- Presence of obstructions to piles/anchors, including services and adjacent structures/basements etc.

In SANS 10160-5:2011, Annex A classifies geotechnical works into four categories (as in Table 3.1 of Chapter 3). Investigation that involves excavations fall into Category 2 and therefore requires the geotechnical investigation to provide quantitative data for the design of lateral support (clause A.2.2).

SANS 1200D:1988 (Earthworks) establishes a method of classifying the excavatibility of materials into five classes, namely soft materials, intermediate materials, hard rock, boulder excavation class A and boulder excavation class B materials (clause 3.1). SANS 634:2012 requires the same classification of materials. This classification is given in Table 4.6 as per Table 5 of SANS 634:2012.

*Table 4.6: Classification of excavation material (as in Table 5 of SANS 634:2012).*

| Excavation | Classification of material | Description |
|---|---|---|
| Restricted | Soft | Material which can be efficiently removed by a back-acting excavator of flywheel power > 0.10 kW for each millimeter of tined bucket width. |
| | Intermediate | Material which can be removed by a back-acting excavator of flywheel power > 0,10 kW for each millimeter of tined bucket width,<br>or with the use of pneumatic tools, before removal by a machine capable of removing soft material. |
| | Hard Rock | Material that cannot be removed without blasting or wedging and splitting. |
| Non-restricted | Soft | Material which can be efficiently removed or loaded, without prior ripping, by any of the following:<br>a) a bulldozer or a track-type front-end loader with an approximate mass of 22 tonnes and 145 kW flywheel power.<br>b) a tractor-scraper unit with an approximate mass of 28 tonnes and 245 kW flywheel power, pushed during loading by a bulldozer equivalent to that described in (a) above. |
| | Intermediate | Material that can be efficiently ripped by a bulldozer with an approximate mass of 35 tonnes and 220 kW flywheel power. |
| | Hard Rock | Material that cannot be efficiently ripped by a bulldozer with an approximate mass of 35 tonnes and 220 kW flywheel power. |
| | Boulder class A | Material containing more than a volume fraction of 40 % of boulders of size between 0,03 m3 and 20 $m^3$, in a matrix of soft material or smaller boulders |
| | Boulder class B | Material containing a volume fraction of 40 % or less of boulders of size between 0.03 m3 and 20 $m^3$, in a matrix of soft material or smaller boulders. |

## 4.7 Linear Structures: Roads, Railway Lines and Pipelines

### 4.7.1 Applicable Standards

The codes and standards most relevant to investigations for linear structures are:

- SAICE (2010) Site investigation code of practice,
- SABS 1200D:1988 Earthworks,
- SABS 1200DB:1989 Earthworks (Pipe Trenches)
- SABS 1200LB:1983 Bedding (Pipes)
- SABS 1200M:1996 Roads (General)
- S410:2006 Spoornet Technical Specification for Railway Earthworks,
- TRH 4:1996 Structural Design of Flexible Pavements for Interurban and Rural Roads,
- Colto:1998 Standard Specifications for Road and Bridge Works for State Roads Authorities.

### 4.7.2 Objectives of Investigation

The main objectives of geotechnical investigations for roads and railways are to provide information for the assessment of subgrade conditions (soil and groundwater), excavatibility and stability of cuttings, and construction materials. Similarly, investigations for pipelines aim to assess the excavatibility and stability of pipe trenches, presence of groundwater and suitability of materials for pipe bedding and backfill.

### 4.7.3 Specific Requirements

Table 1 of the SAICE (2010) Code of Practice (clause 2.6) specifies the minimum number of data points required for investigations for linear structures. Note that data points do not refer to a specific investigation method (can be test pits or boreholes). This is shown in Table 4.7.

*Table 4.7: Minimum number of data points required for linear structures (extracted from SAICE (2010) Table 1).*

| Development | Phase | No. of data points |
|---|---|---|
| Pipeline | Feasibility | 1 per km |
| | Design | 4 per km |
| Road/Rail/Conveyor | Feasibility | 2 per km |
| | Design | 5 per km |
| Canal | Feasibility | 1 per km |
| | Design | 4 per km |
| Power Transmission | Feasibility | 1 per km |
| | Design | 4 per km |
| Tunnels | Feasibility | 2 per km |
| | Design | 5 per km |

SANS 1200D:1988 Earthworks specifies classification of excavation characteristics (clause 3.1) by describing the behaviour of the machine (excavator) in different types of materials. See section 4.6.3 and Table 4.6. Further requirements for the excavation for general earthworks and structures are set in clause 5.2.2.

Road building materials in South Africa are classified as G1 – G10 materials. This classification requires grading and indicator tests, mod AASHTO maximum dry density (MDD) tests and Californian Bearing Ratio (CBR) determinations. The classification of materials using this system is given in the following:

- Table 3402/1 and 3402/2 of COLTO (1998), and
- Table 3A and 3B of SABS 1200M:1996.

These classifications are given in Appendix B1 and B3 respectively.

The classification is based on grading (including grading modulus and maximum size); Atterberg limits; strength (CBR or unconfined compressive strength (UCS)); CBR swell; durability; presence of soluble salts; type of parent material; flakiness index; number of fractured faces and compaction requirements.

Classification of road and rail subgrades requires grading and indicator tests, mod AASHTO MDD and CBR determinations plus determination of in situ CBR using DCP tests. These requirements are given in Sections 6.5 and 6.6 of TRH 4:1996.

Section 6.5 gives the "material depth" over which the CBR of the material will influence the performance of the road pavement. This depth ranges from 1.2 m for road category A to 0.7 m for road category D as specified by Table 15 of TRH 4:1996 (see Table 4.8).

*Table 4.8: Material depths for design CBR of in-situ subgrade, as per Table 15 of TRH4: 1996.*

| Road Category | Material Depth (mm) |
|---|---|
| A | 1000 - 1200 |
| B | 800 - 1000 |
| C | 800 |
| D | 700 |

Section 6.6 deals with the design of in-situ subgrade and Table 16 of TRH 4: 1996 set requirement for subgrade classification, as shown below.

*Table 4.9: Subgrade CBR of classification, as per Table 16 of TRH4: 1996.*

| Class | Subgrade CBR (%) |
|---|---|
| SG 1 | > 15 |
| SG 2 | 7 to 15 |
| SG 3 | 3 to 7 |
| SG 4 | < 3 |

It is also required that special measures such as stabilization (modification of in-situ material) or removal and replacement be implemented where the subgrade classifies as SG 4, following which the subgrade is then re-classified as SG 1, SG 2 or SG 3.

Similar to COLTO (1998) and SABS 1200M:1996, Table 13 of TRH 4: 1996 specifies characteristics for different types of materials including among other, granular material, modified materials and stabilised (cemented) materials. In addition, TRH14:1985 specifies the characteristics for granular material, gravels and soils. A summary of the TRH 14 classification system is given in Appendix B2 (SAPEM, 2013).

The S410:2006 Specification for Railway Earthworks lays down the requirements for railway formations. Clause 6 deals with the properties and classification of materials for placing purposes. Table 1 of S410:2006 specifies material properties for earthwork construction as shown in Table 4.10.

*Table 4.10: Specification of material properties for earthwork as per Table 1 of S4140:2006.*

| LAYER | MATERIAL PROPERTIES | | | | | | | | | | Minimum compaction % of modified AASHTO Density | Minimum strength after compaction CBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SAR Index | | Min. Grading Modulus | % By Mass Passing Sieve (sieve size in mm) | | | | | PI | Max. CBR Swell | | |
| | | | | 75 | 13.2 | 2.0 | 0.425 | 0.075 | | | | |
| SUB LAYERS | SSB | <50 | 2.0 | 100 | 60-85 | 20-50 | 10-30 | 5-15 | 3-10 | 0.5 | 98 | 60 (0) (1.5-3 MPa) |
| | SB | <80 | 1.8 | 100 | 70-100 | 20-60 | 10-40 | 5-20 | 3-10 | 0.5 | 95 | 30 (0) (1.5-3 MPa) |
| **A** | <110 | | 1.0 | | | | | <40 | <12 | | 95<br>100* | 20 |
| **B** | <155 | | 0.5 | | | | | <70 | <17 | | 93<br>98* | 10 |
| **Bulk earth works** | | | | | | | | | <25 | 2 | 90<br>95*5 | 5 |

SABS 1200 LB: 1983 Bedding (Pipes) lays down specifications for different types of materials including selected granular material (clause 3.1), selected fill material (clause 3.2) and bedding (clause 3.3) to be used during construction of pipelines. These specifications are summarised below:

*Table 4.11: Material classification for bedding (pipes) as in clause 3.1 to 3.3 in SABS1200LB:1983.*

| Material Type | Specification |
|---|---|
| Granular material | Granular, non-cohesive material. Singularly graded between 0.6 mm and 19 mm.<br>Free-draining with a compatibility factor of $\leq 0.4$ |
| Fill material | Material with PI $\leq 6$. No vegetation, lumps and/or stones of diameter > 30 mm present. |
| Bedding | For ridged pipes, material of Class A, B, C or D. in accordance with clause 5.2<br>For flexible pipes, selected granular material and selected fill material. |

In clause 3.5 of SABS 1200 DB: 1989 Earthworks (Pipe Trenches) requirements for backfill material in areas subject to loads from traffic is given as:

*Table 4.12: Specification for backfill material as given in clause 3.5 of SABS 1200 DB:1989.*

| Backfill Material | Specification |
|---|---|
| Areas subject to loads from traffic | - PI ≤ 12<br>- Minimum CBR of 15% in the upper 150 mm of subgrade<br>- Minimum CBR of 7% if placed lower in subgrade |
| All other areas | Little or no organic material<br>Exclude stone particles > 150 mm<br>Material must be placed without voids and compacted to avoid settlement<br>Unstable material includes materials containing > 10% rock and material containing large clay lumps that do not break up during compaction |

The standard requires the selection of granular and fill materials to comply with the requirements set out in clause 3.1 and 3.2 of SABS 1200 LB: 1983 as shown in Table 4.11 above.

## 4.8 Conclusion

The purpose of this chapter was to set out specific requirements for site investigations of various types of geotechnical works. In the chapter which follows, examples will be given of problems that can occur if these requirements are not followed.

# Chapter 5: Case Histories

"Ask of the steel, each strut and wire, what gave it force and power."

- *Joseph B Strauss*

## 5.1 Introduction

Despite the geotechnical investigation requirements set out in the previous chapters for different types of development, geotechnical failures caused by inadequate investigation still occur on a regular basis. This chapter illustrates deficiencies in current investigation trends that appear to be occurring in practice. Deviations from geotechnical investigation requirements for four of the development types (townships, houses, piled foundations and excavations) discussed in the previous chapter are evaluated by means of case studies of real projects. The case studies are summarised to extract the most significant information, to provide the reader with the background knowledge and a general understanding of each instance. The focus is however placed on factors that directly contributed to geotechnical failures. The causes of failures will be further elaborated in the final chapter.

Although the cases presented illustrate the inadequacy of site investigations in practice, it is not the intention to imply fault on the part of any geo-professionals. It is simply to identify the factors that contributed to these problems. Therefore, no reference is made to any of the parties involved in these investigations and only general terms such as contractor, client, developer, engineer or investigator are used. In some instances, the details are not in the public domain or are sub-judice which limits the amount of detail that can be provided.

No case studies were analysed for development on dolomite land and linear structures. It was however deemed part of this chapter because it provides the reader with an overview of the progress that has been made in terms of continuous improvements to better the quality of geotechnical investigations for these types of developments.

## 5.2 Township and Housing Development

Geotechnical investigations requirements for township development and housing development are fairly similar and interrelated and can therefore be grouped together for the purpose of this chapter. Four case studies are presented relating to investigations for houses and townships:

- Slope Instability – Cape Peninsular
- Landslide – Southern Cape coast
- Golf Estate – Gauteng Province

- Mass Housing Project – Free State Province

### 5.2.1 Cape Peninsular – Slope Instability

Information relevant to this case were primarily obtained from a geotechnical investigation conducted by engineering consultants in October 2015, to establish the reasons for slope instability on a number of erven (Jones & Wagener, 2015).

#### 5.2.1.1 Site Description

The concerned site is located along the Atlantic seaboard, at the foot of the Twelve Apostles mountain range, adjacent to Table Mountain. Figure 5.1 shows an overall view of area and its proximity to Table Mountain, and an enlarged detail showing the site where the respective properties can be seen in plan-view.


*Figure 5.1: Site locality and respective properties (after Jones & Wagener, 2015).*

#### 5.2.1.2 Background

Between March and July 2008, excavations took place simultaneously on Erven A and B. Heavy rainfall occurred between the end of July and early August and slope movement took place on Erven A and B, on the adjacent property (Erf C) and the two properties situated upslope of the excavations (Erven D and E). Figure 5.2 shows the positions and approximate layout of the properties involved in this case study.


*Figure 5.2: Erven location and layout oblique view (Google Earth, 2017).*

#### 5.2.1.3 Sequence of events relating to slope instability

The events that took place on the five erven are summarised below in terms of periods of excavation and slope movement.

**1980's**

Excavations were formed on Erven B and C around 1982 and a house with a retaining wall on the upslope side was built on Erf B. Cracking on both structures was noted. Slope movements caused by these excavations affected Erven D and E situated above the stands where excavations and development were taking place. Erf E was occupied by an old house with no pool. Erven A and D were undeveloped.

**1990's**

Further excavation was undertaken on Erf C resulting in renewed movement of the slope. A house and pool was built on Erf D around 1994. Erf E underwent extensive alterations, including the building of a pool and a pool terrace around 1998. Erf A was still undeveloped.

**2000's**

Erven A, B, C and D were occupied. Erf A was in the process of being developed and excavation for and construction of retaining walls started in 2008. At the same time, excavation for a new garage took place on Erf B, exposing pre-existing damage to the lower storey of the structure. No geotechnical investigation was undertaken for either excavation. During July 2008, a mound of earth and the stone retaining wall between Erf A and Erf B was removed. The major movement occurred during a period of heavy rainfall between 28 July and 01 August 2008.

#### 5.2.1.4 Description of Failure

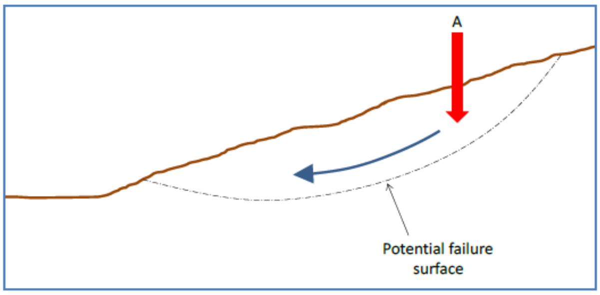
According to data from survey points installed on erven A, B, D and E just days before the major movement occurred and monitored between 2008 and 2011, the bulk of the recorded slope movement on Erf A took place between the 28 July and 6 August 2008. The movement vectors indicated a rotational slip failure with downward movement over the upper portions of the slope and heave at the toe. This is distinct from a translational slide which occurs along a planar failure surface parallel to the slope (Turner and Schuster, 1996).

The occurrence of this slip caused distress to adjacent structures as shown in Figure 5.3. The extent of cracking and pattern of ground movement is indicative of a deep-seated landslip.

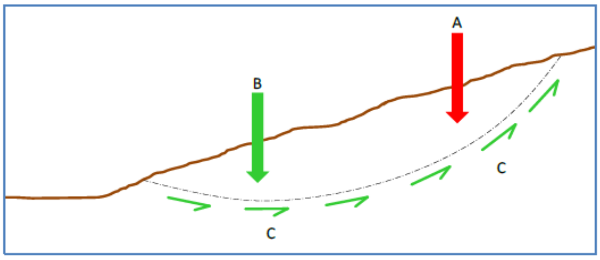
*Figure 5.3: Step in ground level and cracks in adjacent properties (Jones &Wagener, 2015).*

As stated in the timeline of events, all the properties have undergone excavations in the last forty years. The effect of removal of the ground is illustrated diagrammatically in Figure 5.4.

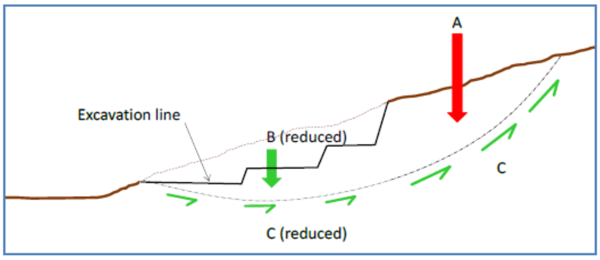
Note that for a slope to remain stable, the net effect of the resisting forces must be greater than the net effect of the disturbing forces. If development is to take place on the slope, it is good practice to ensure that the net effect of the resisting forces is at least 1,3 times the net effect of the disturbing forces, i.e. the slope has a factor of safety of at least 1,3. A slope that has a factor of safety of less than 1.3 may stand but is regarded as unsuitable for development due to the inadequacy of the safety margin. The closer the factor of safety is to 1.0 the more sensitive the slope is to disturbance and the more prone it is to creep movements.




**Slope in natural ground**
On sloping ground, the weight of the soil at the top of the slope (A) acts as a de-stabilising force encouraging the soil to move down the slope in the direction indicated by the curved arrow, along a potential failure plane in the ground.




**Equilibrium of forces acting on slope**
This tendency for the soil to move down the slope is resisted by the weight of the soil at the toe of the slope (B) and by the shearing resistance of the soil (C). The slope is in equilibrium if (B) and (C) is sufficient to counteract the destabilising effect of (A)




**Effect of excavation**
Excavation of soil near the toe reduces the weight of soil at the toe (B) and the frictional component of the shear strength below the excavated area. Depending on the initial state of the slope and the extent of the reduction, if both (B) and (C) are reduced, the slope may become unstable.

*Figure 5.4: Forces acting on a natural slope*

The formation of an excavation at the toe of the slope has two effects. Firstly, it reduces the weight of the soil at the toe (B). Secondly, in the case of a soil that derives part of its strength from friction, it reduces the shearing resistance of the soil (C) over the part of the failure plane below the excavated area. If the stability of the slope prior to excavation was already marginal, the formation of the excavation could cause failure of the slope. Note that it is not the excavation itself that fails, but the slope in which the excavation has been formed.

It is concluded that the cause of ground movement and damage to properties slope failure. Furthermore, although the failure occurred during the reduction in load occasioned by the excavation on the last developing property (Erf A), the movement was essentially caused by the cumulative effect of numerous excavations along the eastern side of Barbra Road dating back to the 1980's.

### 5.2.2 Landslip – Cape South Coast

This particular incident was investigated by a consulting engineering company and published as a case study by South African Institution of Civil Engineering (SAICE) in April 2017. Information were obtained from this publication (Beales & Paton, 2017).

#### 5.2.2.1 Background

Two group residential complexes in Mossel Bay on the Southern Cape coast have been declared disaster areas and residents of approximately twenty-nine houses were ordered to evacuate the area due to significant vertical and lateral displacement of the ground. These two complexes are situated in an old quarry that had been rezoned for residential development in 1999. Refer to Figure 5.5 for an aerial view and zoomed-in image showing the affected area.


*Figure 5.5: Site locality and oblique view of residential area (Beales & Paton, 2017).*

Ground movement was initially noted towards the end of 2015 when cracking and structural distress as well as damage to municipal infrastructure was observed at several residential properties in this area. Figure 5.6 shows the effect of ground movement on several buildings.

*Figure 5.6: Cracks observed in structures around residential area (Beales & Paton, 2017).*

Findings of a preliminary geotechnical investigation commissioned by the Home Owners Associations of the two affected complexes indicated the development of a deep-seated landslip between the two complexes (Beales and Paton, 2017). The Mossel Bay Municipality commissioned a detailed geotechnical investigation to determine the trigger mechanism and depth of failure for recommendations and solutions to be proposed.

#### 5.2.2.2 Geology

Given that the failure appeared to have happened deep below ground level, the geology of the site was a fundamental aspect in understanding the origin and mechanism of this landslip. As reported by Beales and Paton (2017), the affected area is underlain by a thick sequence of sediments of the Uitenhage Group, which consists of the older Kirkwood Formation overlain by the younger Buffelskloof Formation.

The Kirkwood Formation which is exposed on the lower part of the site, consists mainly of mudstone and fine sandstone that was deposited in a low-energy fluvial environment and the Buffelskloof Formation, which consists of thick sequences of alluvial sand, gravel and cobbles (conglomerate), is exposed on the upper part. The contact between the two formations dips towards the base of the slope and is exposed along the steep embankment between the two residential complexes (Beales & Paton, 2017).

#### 5.2.2.3 Detailed Investigation Outcomes

Investigation methods used to further investigate the problem included excavation of test pits and rotary core borehole drilling across the site, samples collected for laboratory tests to determine shear strength parameters of Kirkwood clay, continuous Surface Wave (CSW) tests for assessment of ground stiffness and slope stability analysis using computer software.

Beales and Paton (2017) reported that the results of the investigation include the following:

- Borehole data was used to construct a geological model that indicates a sloping palaeo-channel in the Kirkwood clay, which is now filled with Buffelskloof Formation conglomerate.
- The CSW test results clearly indicate that the upper Kirkwood Formation was of a very low stiffness / soft consistency (Refer to Figure 5.7, left image).
- Consolidated, undrained shear strength test results demonstrated very low cohesion and friction angles that varied between 10° and 21°.
- Microscopic assessment on undisturbed upper Kirkwood material show striations (slickensides) at particle level. This can be seen in Figure 5.7 (right image). It further demonstrates that the upper Kirkwood composed of 88% to 92% clay/silt, has been sheared along distinct failure planes.
- Conceptual 2D slope modelling of failure planes (Figure 5.8, bottom image) illustrate very low safety factors along semi-circular planes in the upper 10m of the Kirkwood clay.

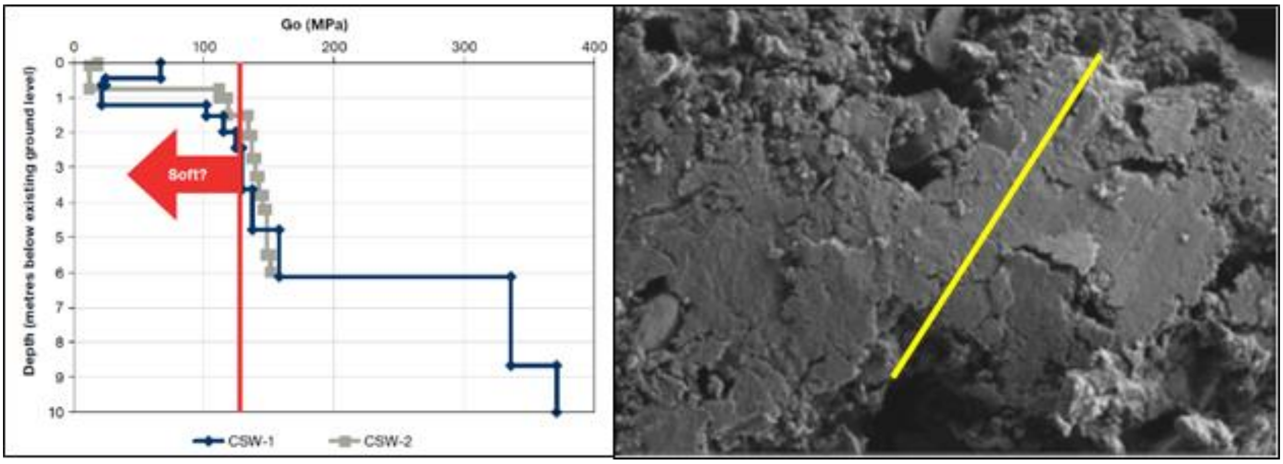



*Figure 5.7: CSW test results (left) and striations on microscopic level (right) (Beales & Paton).*

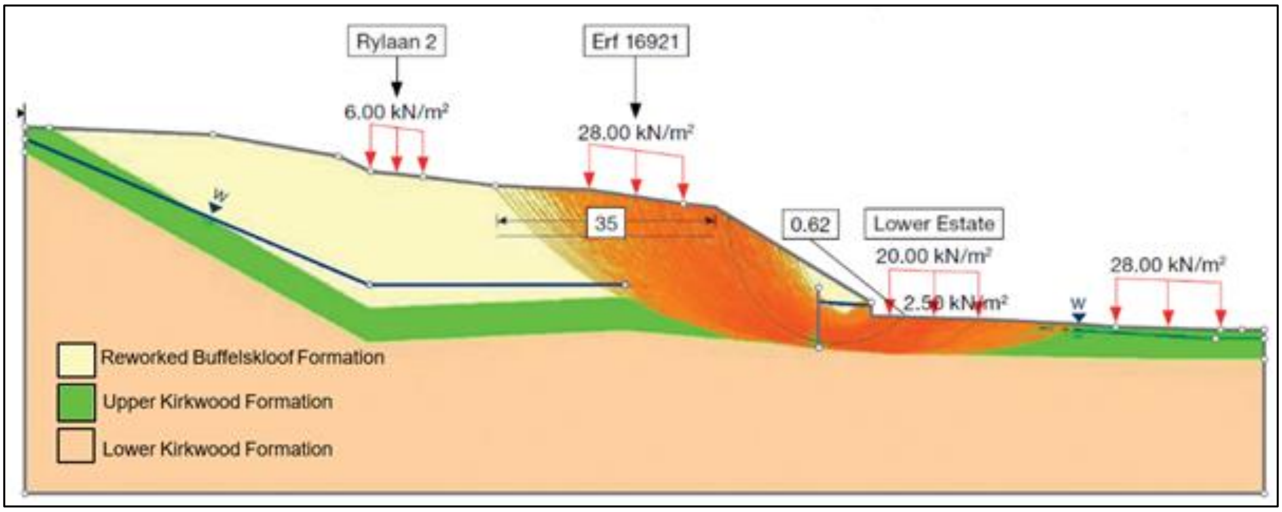



*Figure 5.8: 2- Dimensional slope model (after Beales & Paton, 2017)*

### 5.2.2.4 Conclusion

The detailed investigation established that a deep-seated landslip that is undergoing continuous movement in the upper part of the Kirkwood Formation. Findings of the investigation also indicated that the landslip is susceptible to moisture and needs only a slight increase in moisture content to trigger slope movement. Figure 5.9 shows a major tension crack in the ground with a zoomed in image showing the vertical displacement of the crack.

The landslip has already caused severe damage to approximately 45 houses to date. It is noted that it is common for a landslip of such magnitude to result in secondary slips, further increasing the geotechnical risk of the area. Even if a solution to this problem exists, the cost will be extremely high which obviously complicates the possibility of rehabilitating the affected area. It is therefore important that developers and local authority take note of this problem and realize the possibility of potential geotechnical problems in this area.

*Figure 5.9: Size and displacement of tension crack in the ground (Beales & Paton, 2017).*

*"This case study highlights one of the most significant geological disasters in recent South African history, and it not only demonstrates the role and responsibility of civil engineers in our society, but also the potential scale of emotional distress caused to society when geotechnical uncertainty is not defined and interpreted."* (Beales & Paton, 2017)

### 5.2.3 Golf Estate - Gauteng

#### 5.2.3.1 Site Description

The golf estate concerned is situated on Gauteng's East Rand. The mater is *sub judice* and, as a result, the location, details and sources of information cannot be disclosed.

#### 5.2.3.2 Background

Before the development of the estate in 2007, extensive quarrying operations were carried out in the area. According to the geological map series (1:250 000 Geological Map, Sheet No.2628 East Rand,) the site geology predominantly consists of recent deposits, comprising alluvium sands, clays and gravels as well as Aeolian sands overlying weathered granites and granite gneiss. Mining operations primarily comprised the extraction of sands from the granites.

Construction of a double storey house and swimming pool on a particular stand within the estate was completed in late 2011. Since completion of the structure which covers an extensive portion of the site, significant cracking has occurred both to the house and the adjacent swimming pool. Photographs showing some of the cracks are given in Figure 5.10 below.

*Figure 5.10: Cracks observed in the walls of the house.*

#### 5.2.3.3 Historical Overview of the Developed Area

Prior to 2000, extensive quarrying operations were carried out in several pits for the extraction of sand for commercial purposes. The granitic sands removed from the quarry contained significant quantities of kaolinite (clay) which was washed from the sand as a waste product and stored in various dumps / lagoons, mainly over the southern portion of the area where the concerned property is now situated.

GoogleEarth imagery of the area, over the period of 2002 to 2013 illustrates the condition of the site development at various stages during this period. For confidentiality reasons, these images cannot be reproduced. The following can be concluded from these images:

- Rehabilitation of the site, mainly in the form of flattening the steep western sidewall of the main pit, started in the latter half 2000. The 2002 image however shows the disturbed condition of the area after mining/quarrying operations had been abandoned
- In the 2006 image, a tailings impoundment (what appears to be a silt dam) can be seen in the vicinity of the property.
- By June 2007, most of the undulations on the site had been filled and township development (roads and services) was in progress.
- Most of the estate was developed by 2013, including the concerned property.

#### 5.2.3.4 Geotechnical Investigations

Three geotechnical investigations were done on the site, the first in 2003, then in 2007 and the last in 2013.

The Phase II Investigation was done in 2003 prior to rehabilitation of the site. In the vicinity of the stand in question, it showed 900mm of sandy mine residue overlying dense to very dense residual granite towards north-north-east of the stand.

The 2007 Phase II Investigation was conducted after engineering fill has been placed across the developed site. Various investigation methods were used during the investigation. Test pits were excavated to an average depth of 1.8m in the engineered fill material. DPSH penetration tests were carried out adjacent to the test pits.

The 2007 investigation classified the township in terms of the NHBRC classification system. Portions of the site were designated S1 (10-20mm total settlement) and portions of the site S2 (>20mm total settlement). The stand concerned was classified as S1. It was further recommended that detailed foundation investigations be considered for all types of foundations to be constructed in the area.

Prior to commencement of construction, test pits were excavated on the erf in question which confirmed presence of fill material, as expected from the 2007 investigation. The site classification form produced on conclusion of the 2007 investigation was submitted to the NHBRC in support of application for enrolment.

In 2013, after cracking of the structure occurred, an independent geotechnical site investigation was conducted to determine the cause cracking on the concerned property. The investigation comprised test pits, the collection of soil samples for laboratory testing and carrying DCP tests adjacent to and inside the test pits. Findings of the investigation include the following:

- Engineered fill between depths of 1.0 m and 2.6 m was encountered in all four test pits.
- The material below the engineering fill to the north of the property, describes as "very moist, yellow, soft, laminated, clayey silt" corresponds to the old mining tailings.
- Laboratory tests classified this material predominantly as "silty sands" and "clayey silts". The clayey silt layer was found to be 86% dispersive.
- DCP tests results showed lower consistency than described in the field, but no significant difference in the penetration resistance of the tailings and the overlying fill.

The investigation concluded that cracking of the house is an effect of ongoing settlement of the foundations due to consolidation settlement of both the fill and natural soil underlying the site, and possible shrinkage of a layer of tailings sandwiched between the engineered fill and the underlying natural soil. It further concludes that the settlement could have been foreseen if the recommendations made by the Phase II Investigation in 2003 had been followed.

#### 5.2.3.5 Description of the problem

It is evident from the chronological selection of GoogleEarth images that the area was significantly disturbed by previous mining/quarrying operations. When township development commenced, material from elsewhere (imported fill) were placed on the soft tailings material and compacted in layers.

The Phase 2 township development investigation done in 2007 classified the site according to the NHBRC site classification designations, only in terms of settlement as either S1 or S2 zones. Although the entire area is covered with engineering fill of various thicknesses, the investigation did not classify any portion of the site as P according to the NHBRC's site classification designations (contaminated soils, controlled fill, mining subsidence, etc.).

It is the candidate's opinion that the site was incorrectly classified (S1 instead of P/S1, S2 instead of P/S2). Structures and foundations were therefore designed according to the site classification provided without taking cognisance of the possibility of incompetent layers underneath the engineering fill material.

### 5.2.4 Free State Province – Mass (RDP) Housing Failures

#### 5.2.4.1 Background

This case study is not focussed on a particular incident, but is intended to illustrate that effective geotechnical investigations in areas where deep expansive soil horizons occur is challenging and rarely carried out to the depth and extent required under such conditions.

During 2011/2012 a lot of attention was drawn to low cost RDP (Reconstruction and Development Programme) houses in several Provinces in South Africa. Numerous complaints were made by residents of these houses, relating to planning, procurement, and allocation and, above all, structural defects such as severe cracking. Figure 5.11 depicts cracks in various houses experienced in a number of areas. Appendix C contains more photographs showing the extent of cracking in various houses.


*Figure 5.11: Cracks observed in houses located in various areas (Professor Peter Day).*

#### 5.2.4.2 Geology

Many of the areas that experienced cracking of structures is situated on the Karoo Supergroup. This geological sequence cover the majority of South Africa including of Lesotho, almost the whole of Free State, and large parts of the Eastern Cape, Northern Cape, Mpumalanga and KwaZulu-Natal Provinces (See Figure 5.12 below).

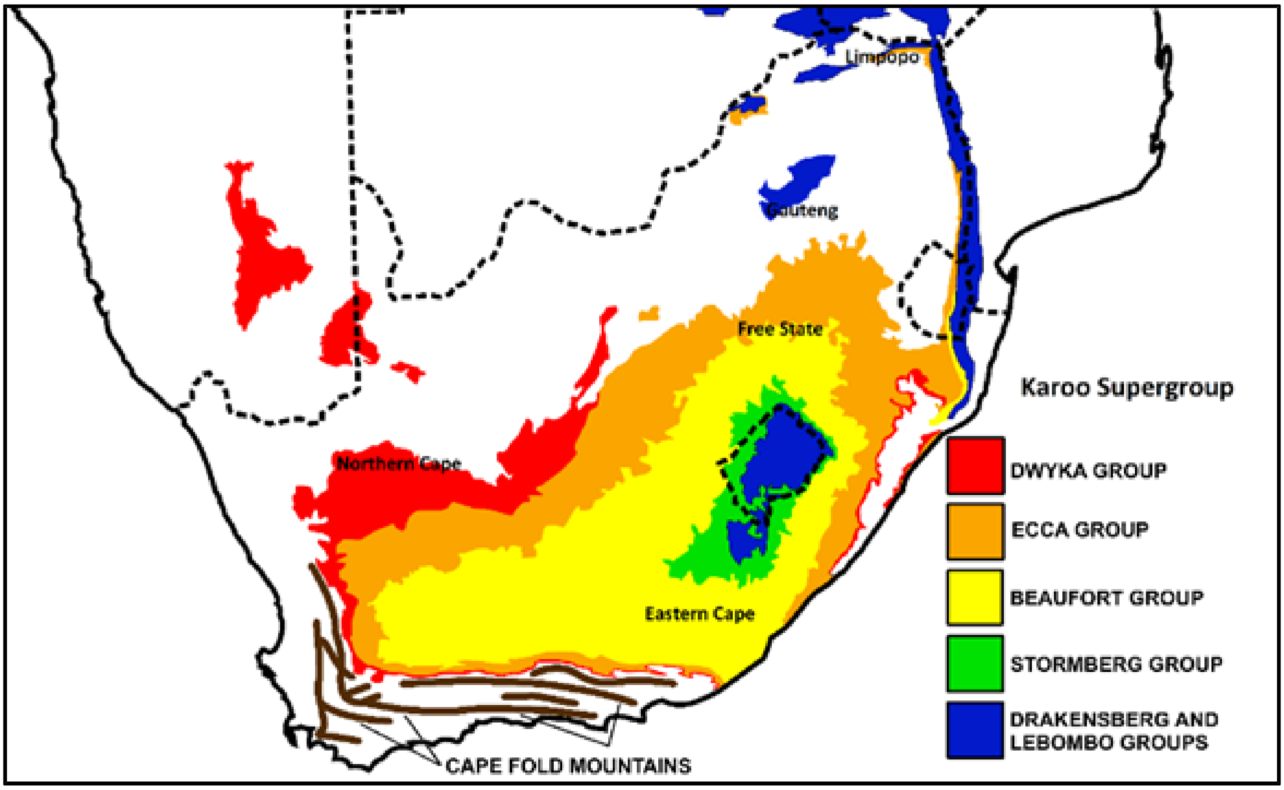



*Figure 5.12: Simplified geological map of Karoo Formations in South Africa (Wikipedia, 2014).*

The Karoo Supergroup comprise mostly sedimentary deposits that include sandstones, shales, siltstones, mudstones and clays. Depending on the nature of the parent rock, climatic environment and type of weathering, the fine-grained sedimentary rocks undergo continuous decomposition and produce profiles of expansive soils. The distribution of expansive soils in South Africa is illustrated in Figure 5.13. These soils undergo volumetric change (swell or shrinkage) as a result of variations in moisture content. In arid or semi-arid areas, the most likely change in moisture content is due to wetting of the soil causing heaving to occur. In the more humid areas, drying out will cause the clays to shrink.

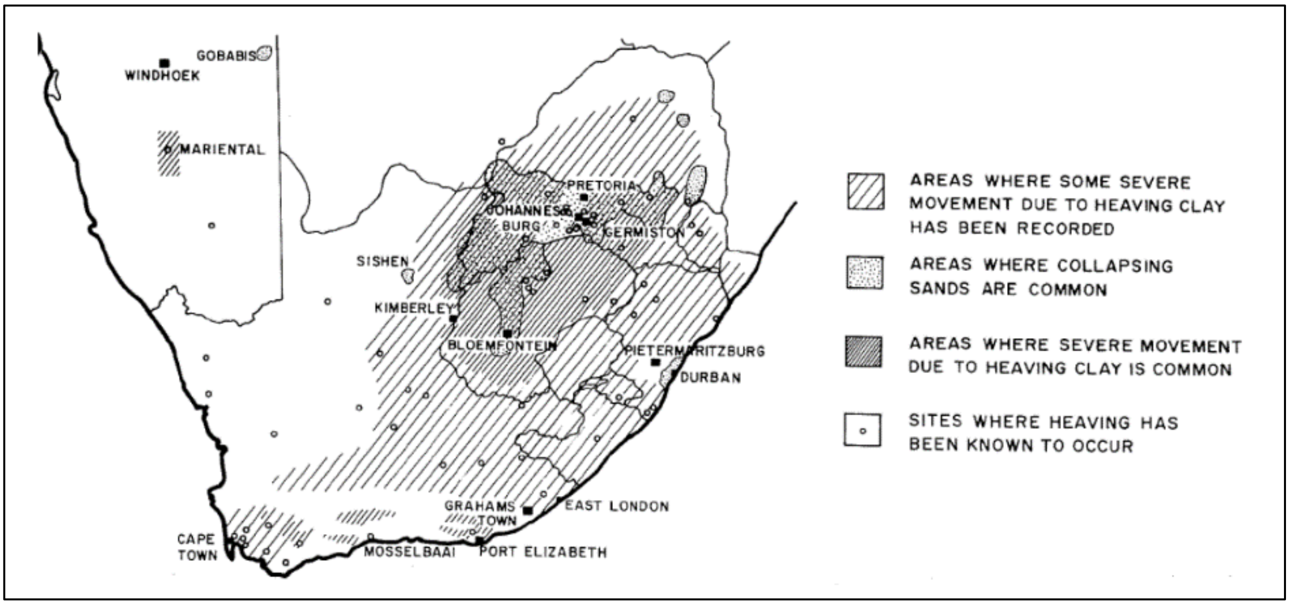



*Figure 5.13: Distribution of expansive and collapsible soils in South Africa (Williams, Pidgeon and Day, 1985).*

#### 5.2.4.3 Discussion

Structural defects in the form of cracking are a result of repeated swelling and shrinking of the soil profile below the structure due to seasonal moisture content changes. In most cases, the structures assume a "corners down" mode of deformation known as central doming.

The problem with the expansive soil profiles of the Karoo Formations is that these often occur to depths of 10m or more (Day, 2013). Despite numerous publications (Van der Merwe (1964); Williams et al (1985); NHBRC (1999); Department of Public Works (2007); Day (2013)) providing guidance on the identification of expansive soils and prediction of heave, the problems persist.

The question that needs to be asked is whether extent of the geotechnical investigations currently being carried out for township development are adequate in terms of depth of investigation and laboratory testing. All too often, these investigations are done using a tractor-mounted loader / backhoe with a maximum reach of 3,5m (compared to the 10m plus thickness of clay) and only limited soil testing is undertaken.

## 5.3 Investigations for Piled Foundations

### 5.3.1 Plettenberg Bay Commercial Building

The information on this site is not in the public domain. As a result, certain details and the source of the information are not disclosed.

#### 5.3.1.1 Background

The construction of the new commercial building, comprising a four storey concrete framed structure with a glazed curtain wall envelope, worth R300-million has been underway since 2015 (Knysna-Plett Herald, 2017). Figure 5.14 shows the site of the proposed structure in 2016, with a zoomed-in image of progress to date.


*Figure 5.14: Site location (GoogleEarth).*

#### 5.3.1.2 Geology

The 1:250 000 scale geological map (3322 Oudtshoorn) indicates that the site is underlain by quartzitic sandstone of the Peninsula Formation. A section of the geological map also showing the surrounding geological sequences is given in Figure 5.15.

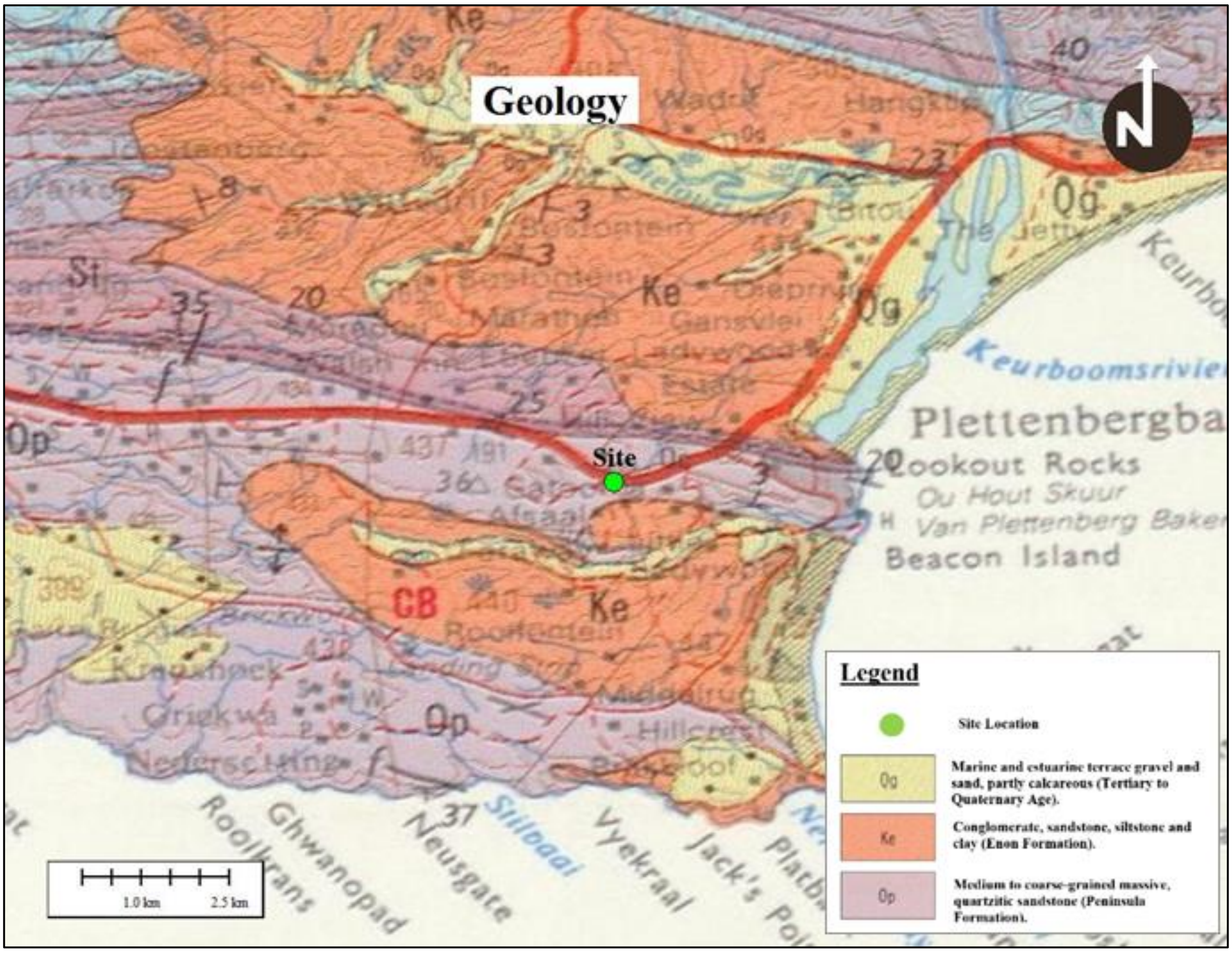



*Figure 5.15: Geological map of the area (extracted from the1:250 000 scale geological map 3322 Oudtshoorn).*

#### 5.3.1.3 Geotechnical Investigation Findings

A geotechnical investigation of the site was done in 2009. It was stated that the development will comprise maximum column loadings (working loads) ranging between 2000 and 4000 kN and a semi-basement with maximum depth of 3.0 m. The initial investigation comprised excavation of four TLB-dug test pit to a depth of approximately 3.0 m, DCP test carried out adjacent to and at the base of each test pit and disturbed soil samples were collected for laboratory testing to determine the soil characteristics, swelling and foundation suitability. Although a shallow rockhead was expected on the quarzitic sandstones of the Peninsular Formation, no rock was encountered.  Two of the test pits were subsequently deepened to 5.9 m during a follow-up investigation with a larger excavator in an attempt to establish the depth of the underlying bedrock.

Findings of the investigation include the following:

- The site was underlain by colluvial soils to the investigation depth of 5.9 m. Neither residual material nor bedrock was encountered in any of the test pits.

- The colluvium generally contains clayey soils (26% – 66%) of high plasticity which occur as stiff to very stiff material between depths of 0.8 m to 1.4 m.
- Soil moisture generally ranged from slightly moist to very moist. No groundwater was encountered.
- In terms of the standard specification TRH 14, both the near surface soils and deeper colluvium classify as a G10 material and will therefore not be suitable for re-use.
- The maximum permissible bearing pressure of the colluvium is estimated to be 200 to 250 kPa, and 300 kPa for deeper-seated material.

The report stated that there will be a significant increase in moisture content during periods of high rainfall and the high clay content will render the colluvium soils susceptible to volumetric change (swell) and alternatively shrink during dry periods. It is therefore important that effective drainage is achieved.

The investigation concluded that piled foundations will be required to transfer foundation loads that exceeds 250 kPa into more competent material. A pile depth of 12m below ground level was suggested for tender purposes. Furthermore, it was recommended that, prior to commencement of piling, exploratory boreholes be drilled to confirm the pile foundation levels as well as an attempt to establish bedrock depth.

#### 5.3.1.4 Description of Problem

No additional geotechnical investigation was undertaken as recommended in the geotechnical report.

It is understood that during construction, pile length considerably exceeded the initial estimate with some of the piled foundations penetrating approximately 25 m into the ground below basement excavation level. Investigation carried out after the problem became apparent indicated that, although the geological map showed the area to be underlain by quarzitic sandstones from the Peninsula Formation, the investigation found more deeply weathered mudstones and siltstones from the Uitenhage Formation instead.

The final cost of the piling was significantly higher than the original tender price. It is noted that the increase in the piling cost was is substantially more than what a proper geotechnical for piled foundations would have cost in the first place.

## 5.4 Investigation for Excavations and Lateral Support

Due to the ongoing demand for commercial space in Sandton with the associated need for underground parking, numerous basement excavations are being undertaken typically ranging in depth from 10m to 32m. Figure 5.16 below shows a number of such excavations in progress during 2015.


*Figure 5.16: Aerial view of excavations in progress during 2015 (Source: GoogleEarth).*

Two of these excavations are described below. Once again, the information on which these case histories are based is not in the public domain and certain details and sources have been withheld.

### 5.4.1 Basement 1

#### 5.4.1.1 Description of development

This 32m deep basement is in the heart of the Sandton CBD adjacent to two major arterial roads.

#### 5.4.1.2 Geotechnical Investigation Findings

The original geotechnical investigation was conducted in June 2007, for the development of a multi storey office block, with basement levels of approximately 9.0 m to 12.0 m deep. The area of investigation covered approximately 9000 m$^2$. The investigation comprised eight hand excavated test pits to a depth of 1.0 m, six auger holes drilled to refusal or termination due to seepage and the collection of disturbed samples for laboratory testing.

The general soil profile comprised existing fill (0.1 - 1.7m), transported hillwash (1.0 - 1.7m), reworked residual granite (1.5 – 3.2m), residual granite (8.0 – 11.0m) and soft rock granite (12.5 – 16.5m). In terms of excavatibility, the site was classified in accordance with SABS 1200DA and DB to be soft excavation to an average depth of 13.5 m, Boulder Class A excavation in large hard rock granite corestones and blasting on very large granite corestones.

It was recommended that stabilization of the cut faces be provided in the long and short term and proposed that soil nails and gunite or perimeter piles with temporary tie-back anchors be implemented as lateral support systems. In addition, it was recommended that the soil nails and/or anchors placed along the boundaries of the site extend into the road reserves. The investigation suggested that piled foundations be used for the proposed structure.

In the interim, the depth of the excavation was changed to a maximum of 32m but no further investigation was undertaken.

The second geotechnical investigation was conducted in August 2014 by the geotechnical contractor appointed for the design and installation of lateral support systems at a time when the excavation was already well advanced. This investigation was motivated by evidence of residual soils to greater depths than originally envisaged, extending in places to virtually the full depth of the excavation. As a result, the depth of soil to be supported was greater than the depth for which the lateral support had been designed and the soldier piles were not founded on rock as originally intended. This second investigation comprised washboring through the soils overlying the rock followed by rotary core drilling at twelve specifically selected pile positions around the perimeter of the site inside the basement excavation. In places, wash boring in soils was possible to depths of up to 14.35m below the current excavation level. In addition to the granites of the Halfway House Formation found during the initial geotechnical investigation, the 2014 geotechnical investigation revealed the presence of diabase dykes and sills.

#### 5.4.1.3 Description of Problems Encountered

During the design of the excavation, the depth of the bedrock around the perimeter of the excavation was extrapolated from the widely spaced auger holes of the 2007 investigation, some of which did not encounter bedrock. This information appeared to indicate that the bedrock was at an average depth of about 15m below natural ground level. The soldier piles and lateral support were installed accordingly. As the excavation progressed to the 15m mark, it became apparent that the rockhead was highly variable and that, over large portions of the perimeter of the excavation, the residual soils extended well below the base of the soldier piles. The second investigation done by the geotechnical contractor from inside the excavation showed that these soils extended to virtually the full 32m depth of the planned excavation in places.  As a result, the lateral support had to be re-designed and the excavation had to be partially backfilled around the perimeter to allow for the installation of additional, longer anchors. Figure 5.17 show the backfill around the perimeter of the excavation.

*Figure 5.17: Backfill around the perimeter of the excavation.*

The movements associated with the deeper excavation resulted in distress to adjacent buildings, which fortunately belonged to the same owner, and to the adjacent streets.  The increased cost to the project including programme delays far exceeded the cost of conducting a competent geotechnical investigation from the outset, in accordance with the requirements of the codes.

### 5.4.2 Basement 2

#### 5.4.2.1 Description of Development

This was a smaller excavation than Basement 1 and extended to a depth of between 14m and 22m below ground level.  The buildings within the basement were to be founded on spread footings placed on rock.  The intention was to excavate in bulk to the level of the underside of the foundations, construct the footings and then backfill between the footings rather than forming individual foundation excavations in the rock.

#### 5.4.2.2 Geotechnical Investigation Findings

The first geotechnical investigation was conducted by a consultant in October 2007, for the development of a multi storey office block, with a triple basement. The investigation comprised twenty-three auger holes drilled to refusal of the rig and the collection of disturbed and undisturbed samples for laboratory testing.

According to the 1:250 000 geological map series of East Rand, the site is underlain by granite of the Halfway House Granite inlier. The investigation found that the granite has been intruded by diabase across the southern end and central portions of the site.

The general soil profile comprised existing fill (0.2 - 1.5m), transported hillwash (0.3 – 3.0m), reworked residual granite (2.0 – 6.4m), residual granite with hard rock granite corestones between 3.7m and 5.4m within the reworked and residual granite layer in two of the test pits and soft rock granite (9.6 – 16.0m). Where diabase was present, the residual soils extended to 13.3m followed by soft rock diabase to 14.5m.

In terms of excitability, the site was classified in accordance with SABS 1200DA and DB to have soft excavation to an average depth of 13.0 m, Boulder Class A / intermediate excavation on hard rock granite corestones, hard rock excavation and blasting on granite, localised diabase bedrock and larger corestones that were encountered in four of the twenty-three test pits.

It was recommended that stabilization to the cut faces be provided in the long and short term and proposed that soil nails, gunite, perimeter piles with temporary tie-back anchors or steel solider with temporary tie-back anchors be implemented as lateral support systems. In addition, it was suggested that piled foundations be used for the proposed structure.

The second geotechnical was conducted by the same geotechnical consultant in November 2013. The ownership and nature of the development had changed to a multi-storey structure with nine basement levels excavated to approximately 27 m deep. The investigation comprised drilling of six rotary core boreholes to a depth deemed suitable for the scope of the investigation.

Like the initial geotechnical investigation, the same granite with diabase intrusions was found across the southern end and central portions of the site. The general soil profile comprised the same layers at approximately the same depths as in the initial investigation and the excavation classification of the site also remained more or less the same. The positions and depths of boreholes and test pits from the 2007 investigation that was used to assist with this investigation are shown in Figure 5.18 below.


*Figure 5.18: Positions and associated depths of test pits and boreholes.*

It was stated that all cut slopes on the site pose an inherent stability risk and therefore recommended that a suitably designed lateral support system be implemented for the 27m deep basement excavation. Furthermore, the investigation predicted that granite or diabase bedrock, with an allowable bearing pressure of 2000kPa will be intersected across the majority of the site during the basement cut excavations. Therefore, conventional and / or deeper than normal strip / spread foundations were recommended for the proposed structure.

This was followed by an investigation conducted by the lateral support contractor around 2014. This investigation found the following:

- A diabase dyke in the south-west corner of the site and Halfway House granite over the remaining site footprint.
- Granitic rock on the north-west corner was detected at 8m below natural ground level, where the basement excavation extends to its deepest point of a total of 22m.

#### 5.4.2.3 Problems Encountered

During construction, portions of the site were found to be on rock as expected. However, over much of the south-eastern portion of the site, no rock was encountered or the rock was not capable of supporting the design bearing pressures. In places, decomposed diabase was found to underlie weathered granite as shown in the photo below.


*Figure 5.19: Exposed test pit showing material found on site.*

When the problems were observed, further investigation was carried out from the base of the excavation by specialist geotechnical consultants. This investigation comprised drilling of eighteen rotary core boreholes, Continuous Surface Wave (CSW) testing and Dynamic Probe Super Heavy (DPSH) penetration tests carried out from the level of the base of the excavation.

Because of the presence of incompetent founding materials over this portion of the site, foundations sizes were increased and foundation excavations deepened. Every base in the affected area of the site had to be inspected individually. The foundations were either redesigned to found at greater depth or the deepened excavations were backfilled with mass concrete to original founding level.

The result was significant delays and cost increases to the project. The cost of the mass concrete alone would have paid for a competent geotechnical investigation many times over.

## 5.5 Development on Dolomite Land

According to Potgieter (2012), approximately 5 – 10% of South Africa is underlain by dolomite. This include areas in Gauteng, Mpumalanga, Limpopo, Northern Cape and North-West Province (see Figure 5.20).

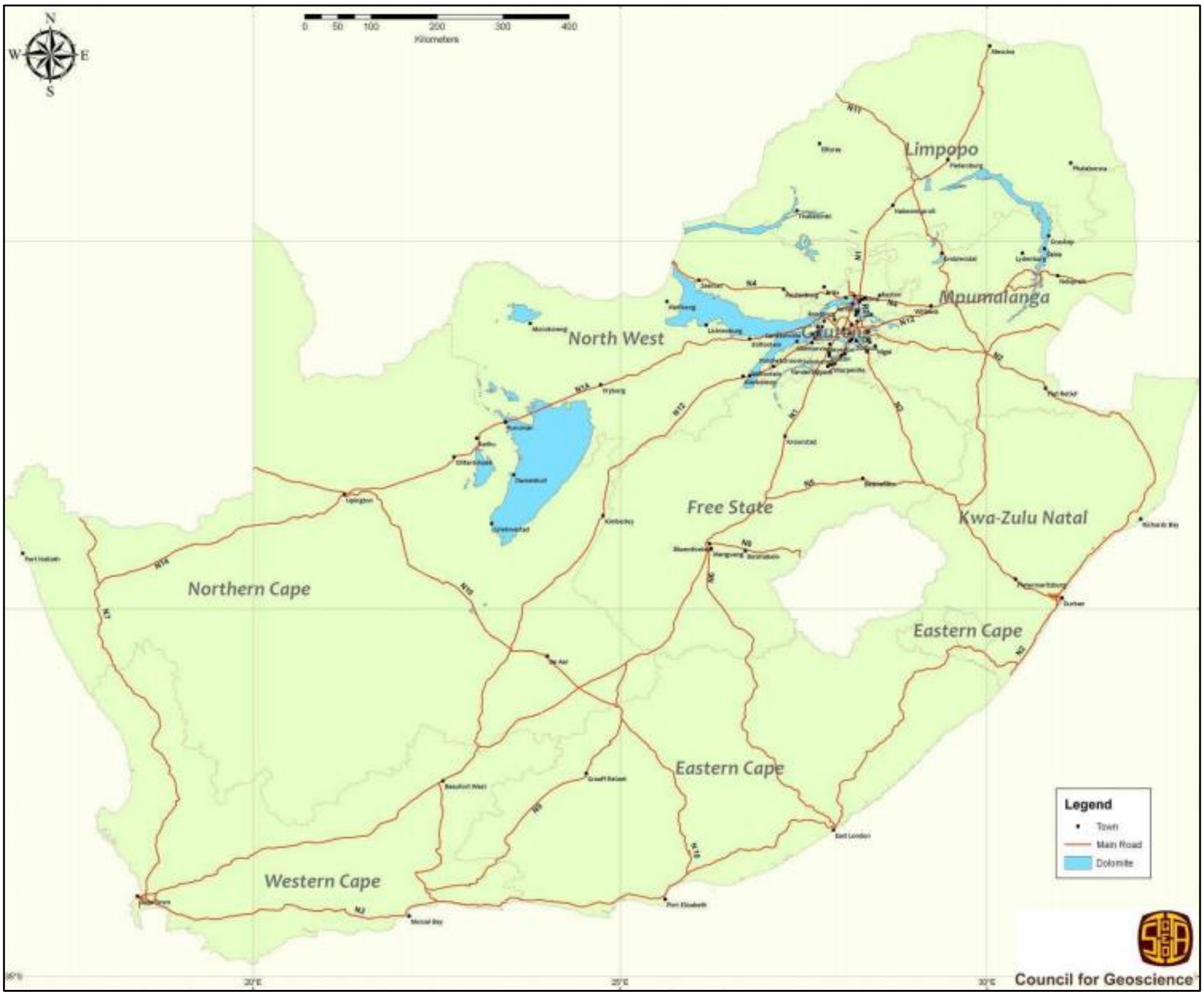



*Figure 5.20: Distribution of dolomite in South Africa (Oosthuizen & Richardson, 2011).*

Although the formation and weathering of dolomite rock is a natural process, the meta-stable state of these environments is commonly disturbed by urban development. Such disturbance is accompanied by the risk of sinkhole formation which often leads to large-scale disasters and even loss of life. The occurrence of numerous sinkhole in the late 1950's alerted provincial authorities of the possibility that this phenomenon might occur elsewhere (Oosthuizen and Heath, 2008). According to Kirsten et al. (2009), risk evaluation for development on dolomite emerged in the early 1970s.

Several studies relating to dolomite land have since been conducted, but first attempts at classifying and zoning land into areas of similar risk was proposed by Buttrick et al., (2001). This method for dolomite land hazard assessment evolved into a generally accepted standard which is currently being used in South Africa and has been incorporated into SANS 1936. Dolomite risk management and mitigation strategies are employed to reduce the likelihood of sinkholes occurring on dolomite land.

Currently, the SANS 1936 (2012) standards forms the basis for the requirements for the sustainable management and development of dolomite land in South Africa. In addition, requirements and guidelines for development on dolomite land are set out by various other regulatory bodies such as the National Home Builders Registration Council (NHBRC), Council for Geoscience (CGS) and Department of Public Works, amongst others. Furthermore, any proposal for development on dolomite land is referred by the Local Authority (for example the City of Tshwane) to the Council for Geoscience prior to being approved.

According to (Buttrick et al., 2011), the implementation of risk management strategies has had a significant impact on the occurrence of ground instability events, reducing ground movement events from 50 events per year in the early 2000s to 5 per year (90% reduction in events). This demonstrates the effectiveness of regulatory measures pertaining to geotechnical investigations in instances where compliance is enforced.

## 5.6 Linear Structures: Roads, Railway Lines and Pipelines

No case studies have been analysed for the development of linear structures for two reasons. Firstly, it is difficult to find cases that is specifically related to geotechnical failures in South Africa over recent years. Secondly, it is in the opinion of the author that linear structures such as roads, railways and tunnels all form part of the transportation system that is a much bigger industry than geotechniques. An overview of the development and compliance of regulations are however given.

The transportation industry in South Africa is a major industry that has been around for many years. Geotechnical investigations are a very important aspect in the provision of roads and have been incorporated into the various pieces of legislation that regulate linear structures (section 4.7.1). Specifications for roads date back prior to the 1980's when the National Department of Transportation (DOT) and Provinces managed most of South African roads. During the 1980's there was a combined effort to develop one set of specifications for road construction in South Africa that is the CASRA Standard Specification for Road and Bridge Work. Subsequently, the CASRA committee was replaced by the Committee of Land Transport Officials (COLTO) during the 1990's. The first publication of the COLTO specification was in 1998. The South African National Roads Agency (SANRAL) has taken the responsibility to maintain and formalise adjustments to the COLTO document and an update to the document was initiated in 2014.

The roads industry still experiences premature failures in terms of road cracks and potholes, but it has come a long way by improving on lessons learned over many years. It was established during an informal interview with Professor Kim Jenkins of who occupies the SANRAL Chair at Stellenbosch University that improvements to the COLTO specification could fit into a couple of areas in terms of the material classifications and its usage for roads. One area relates to the types of tests being done, for example, CBR testing has been done for a long time, but currently triaxial testing is being initiated to get more fundamental parameters that can be linked directly to performance of mix designs for pavement materials. With granular materials that are 95% of the pavement, CBR is still used, test results don't link directly to performance.

As with roads, developments for railways comprise a comprehensive set of requirements that is undergoing continuous improvements to minimize project failures.

## 5.7 Conclusion

The various case studies are an illustration that there are still many pitfalls in the geotechnical industry. Most of these failures relates to the inadequate investigation of subsurface conditions despite the existence of comprehensive standards and guidelines. The cost of these failures is significant, in most instances far outweighing that of an adequate investigation.

The problem is not a lack of knowledge on the procedures to be followed when undertaking geotechnical investigations, it is a failure to apply these standardised procedures.

An overall assessment of these cases are given in the following chapter.

# Chapter 6: Conclusions and Recommendations

"If we desire respect for the law, we must first make the law respectable."

- *Louis D. Brandeis*

## 6.1 Introduction

The case studies in the previous chapter illustrate the various aspects which contribute to geotechnical failures. These include inadequate investigations, varying geological conditions and non-compliance with regulations amongst others. It will be suggested that we may need to look beyond these factors to find a lasting solution to the problem.

This chapter provides an overall assessment of the proximate cause/s of failure in each of the cases presented in Chapter 5. Where relevant, non-compliance with standards is demonstrated by referring to specific clauses in the applicable regulations, standards and codes of practice. Some of these documents may have been updated to more recent versions, but in fairness to those involved, the codes and standards referred to are those that were applicable at the time of the incidents.

Taking into account the research objectives set out in Chapter 1, this chapter essentially focus on the general trends that are currently being followed by the geotechnical engineering profession as well as the consequences thereof. As a result, recommendations arising from the comprehensive discussions in the previous chapter are formulated concisely in this chapter.

It is important to note that the opinions expressed are those of the author and do not necessarily represent the views of any of the bodies that supplied data.

## 6.2 Township and Housing Development

### 6.2.1 Cape Peninsular – Slope Instability

Failure of the slope was due to the cumulative effect of excavations on a number of adjacent stands over a period of years. From the outset, the hillslope was not suitable for township development of the type that has taken place. This is the sort of problem that an investigation in terms of SANS 634:2012 Geotechnical Investigations for Township Development is intended to pick up. However, there is no evidence that such an investigation was undertaken when development in the area first commenced in the 1960s'. To compound matters, it appears that no site-specific investigation was conducted prior to development. As indicated above, advising the client of the need for such investigations is part of the normal to be provided by the engineer. Furthermore, the local authority failed to advise the home owner of the potential for unstable conditions as it was obliged to do in terms of the National Building Regulations F3 (1).

With regards to geotechnical investigations, the following requirements appear to have been breached. The person / authority to whom responsibility for adhering to the requirement in terms of the referenced documents is given in brackets.

- Clause 11(2)(e) of the 2003 Construction Regulations (the latest version at the time of failure), in terms of preventing instability of adjacent development (contractor).
- Clause 3 (1) of the ECSA Code of Conduct (see section 3.4) regarding exercise of skill care and diligence (registered person).
- Section 2.1.1 (5) of the 2005 ECSA Guidelines Scope of Services and Tariff of Fees (section 3.4**Error! Reference source not found.**) regarding informing the client of the need for site o r other investigations (engineer).
- National Building Regulation F3 (1)(b) requiring notification to the applicant of potentially unstable land (local authority).

An important question relating to this failure is, if a site-specific investigation had been done, would it have found the problem given that it appears that the failure occurred 15 m below the ground? A second question is whether the standards that are now in place could potentially prevent reoccurrence of similar problems (a) in the same area or (b) in areas of new development? A case will be made that investigations for new townships in terms of SANS 634:2012 should be sufficiently comprehensive to identify potential problems with slope instability. This task should not be left to the developer of an individual stand.

### 6.2.2 Southern Cape - Landslip

It is apparent that the failure took place on a particularly weak, adversely dipping layer deeper in the soil profile and that is was possibly triggered by erosion. Certain elements of the problem, such as poor soil conditions, groundwater seepage and steep slopes definitely point towards a potential slope failure. Again, an investigation carried out in accordance with SANS 634:2012 should certainly have identified these elements. However, development of the area commenced prior to the inception of this Standard.

The problem lies directly with the failure of the original township development investigation to detect the potential for slope instability, probably because of inadequate depth of investigation. There was no problem with the foundations of individual structures. This problem, like that with the Cape Peninsular case, would not have been picked up by a foundation investigation for individual stands.

The same breaches identified in for the Cape Peninsular case presented above apply and the same questions may be asked.

### 6.2.3 Gauteng Golf Estate – Structural damage to houses

The site was essentially a mining area which was rehabilitated by placement of engineered fill and then developed as a township. It is apparent that a number of geotechnical investigations were carried out prior to the construction of the development. Despite numerous geotechnical investigations conducted for the development of the estate, structural and foundation failures still occurred.

The root cause of the problem on this site was a failure to recognise the effect of settlement of remaining mine spoils at depth below the engineered fill. This caused the stands to be classified as S1 and S2 in terms of the NHBRC requirements (see chapter 5.3) instead of "P" (controlled fill, mine waste fill, etc).

There are several factors that contributed to the foundation failure in this case:

- Incorrect classification of the site at township development stage in accordance with the NHBRC requirements (competent person).
- Failure on the part of the developers to fully disclose the available geotechnical information and history of the development of the site to the developers of individual stands. This is not a statutory requirement but may have assisted in alerting the home owners and their appointed competent person in avoiding the problems.
- The issue of partially completed but signed site classification certificates to home owners by the developer. This reduced the responsibility of the competent person appointed by the home owner to investigate and classify the stands.
- The requirement for additional geotechnical investigation for double storey structures was not adequately adhered to, partly to being poorly communicated and partly due to the issue of site classification certificates.

The problem with this case essentially lies in the method of rehabilitation of this site in preparation for residential development and the way the requirements for precautionary measures were then communicated to owners and designers. Settlement of the foundation is due to factors that could not have reasonably been foreseen in the absence of the information given in the body of the township investigation report which was not made available to developers.

### 6.2.4 Mass Housing (RDP) on Karoo Formations (Free State)

Cracking of houses / structures is a common occurrence in areas underlain by expansive layers the Karoo Formations. This is often the result of seasonal heaving and shrinkage of the soil profile below the structure. The most likely cause of failure is that the NHBRC's classification of individual stands was incorrect and the foundation designs were inappropriate for the site conditions. The nature of the damage (as discussed in Chapter 5.2.4), suggests that the classification of the stands should have been H3 which would have required different foundations to be used and a rational design of the foundations to be undertaken. Such designs require quantitative geotechnical data on soil properties including potential expansiveness, stiffness and (in the case of piled foundations) shear strength over the full depth of the soil profile.

The problem with development on Karoo Formations is that the depth of the expansive material tends to be deep, in some areas greater than 10m. It is unreasonable to expect that the information required for the design of foundations should be determined on a stand-by-stand basis. The cost of such an investigation to the full potential depth of the expansive strata could conceivably be more that the cost of house itself. This information should have been determined during the township investigation stage of the development according to the requirements of SANS 634.

### 6.2.5 Summary for Housing developments

Two key issues emerge from the above case studies which are specific to housing developments:

1. Although SANS 634 requires the identification of geotechnical constraints on development such as problem soils, slope instability, etc., it does not go far enough in quantifying the nature of such problems.
2. It is unreasonable, particularly in the context of sub-economic housing, to perform detailed investigations on individual stands.

The identification of geotechnical constraints and determination of design parameters should be undertaken at township development stage, even if this means amending the requirements of SANS 634.

## 6.3 Plettenberg Bay Piled Foundations

The Site Investigation Code of Practice (SAICE, 2010) and the Franki book (Franki Africa, 2008) clearly identify the requirements of the depth of investigation for piles foundations. The problem on this site was that, as a result of incorrect expectations created by large scale geological maps, and investigation was carried out for spread footings rather than piles. Once the changed geological conditions were recognised, the depth of investigation was increased but was still inadequate.

In recognition of the inadequacy of the investigation for piled foundations, a recommendation was made that further investigation should be carried out by the geotechnical contractor at the start of the contract. In addition, a suggestion was made for the depth of piles to be included in the piling tender. These are both pragmatic actions.

The real problem is that the recommendation for additional investigation made by the geo-professional was not followed at the time of construction. This is classical case of failure in the management of the project and is a stark reminder that members of the professional team other than the geo-professional and the client also have a responsibility to behave in a professional manner. Unfortunately, there are no statutory obligations that compel clients / developers to adhere to the minimum requirements for geotechnical investigations or the recommendations made in their best interest by geo-professionals. Project managers and principal agents are, however, bound by the rules of conduct of their professional registering bodies (ECSA, SACPCMP, etc.).

## 6.4 Investigations for Excavations and Lateral Support

The geotechnical investigations for both the developments in the case studies were conducted using primarily auger drilling rather than rotary core drilling. The investigations did not conform to the requirements set out for investigations for excavations and lateral support as stated in Chapter 4.6. Particularly, failure to comply to the requirements of the SAICE Lateral Support Code (clause 2.2) in terms of depth and extent of the investigation.

The real question to be asked is how such breaches of norms are permitted to occur in the first place. In both these instances, the investigation was carried out well in advance of the commencement of construction, probably with a different type of development in mind. Neither investigation was tailored to the specific project that was finally constructed. Thus, the blame cannot be placed solely on the geo-professional for failure to adhere to the norms for lateral support projects. An equal responsibility rests with the client and the project management team to ensure that the geotechnical information remains adequate for the project that is finally constructed.

The unfortunate reality is that the feasibility of most commercial developments is dictated by the rental earnings potential of the development and the date on which it can be occupied. This has the undesirable result that there is never enough time or budget for a proper geotechnical investigation. The approach seems to be one of providing the bear minimum of information and then dealing with claims as they arise. The liability for the losses suffered is frequently deflected from where it rightly belongs, namely with the persons who elected to proceed on the basis of inadequate geotechnical data in the first place.

## 6.5 Recommendations – Changes Needed (Potential Solutions)

### 6.5.1 Township and Housing Development

Problems encountered with township and housing development stem from the township development phase. In all the cases presented above, the problems would not necessarily have been identified by the type of foundation investigation required for an NHBRC site classification. These problems should however have been picked up at the township development stage in the SANS 634 investigations. The most likely shortfall in a number of cases was that the SANS 634 investigation either did not correctly classify the sites, failed to identify critical geotechnical constraints or failed to provide the information required for foundation design. Note that the latter is not currently a requirement in SANS 634.

It is therefore recommended that the geotechnical investigation requirements for the township development (SANS 634:2012) investigation be widened. As a minimum, investigations requirements for townships and houses should ensure that the full depth of any problem soil horizon is investigated even if this requires some form of deep investigation like rotary core or auger drilling in areas underlain by deep clays or situated on slopes with potential for deep-seated movement. This will require a more comprehensive and detailed desktop study to identify and interpret geological strata and boundaries more accurately and include extensive historical and recent data from the surrounding areas of a proposed development. Given that it is not feasible to drill boreholes on the individual stands / properties, the information yielded by the township investigation must be sufficient, together with information from shallow test pits on the stand in question, to allow informed decisions to be taken on the design of foundation for individual homes. This can be achieved in one of two ways.

1. Revising SANS 634 to ensure adequate depth of investigation and that quantitative design data is provided over the full depth of any problem soil horizon.

2. Compile a standardised specification setting minimum requirements for geotechnical investigations for township development and housing which contain these requirements.

The way the regulations, standards and codes are written at present, the competent person appointed by the individual home owners would be required to undertake additional investigation to provide information not available from the township investigation report. This in not affordable in instances where problem conditions exist at depth. If the above recommendations were to be implemented, all that individual home owners would be required to do is assess the foundation conditions within the upper metre or two of the profile to confirm the validity of the site zoning given in the township investigation report. The exception to this is for sites on dolomite where conditions vary so greatly that additional deep investigation may be required for individual developments, particularly on D4 dolomite sites.

It is also recommended that the NHBRC increase its control over township development. As is the case with dolomite investigations, these investigations require thorough evaluation and should not only be simply be rubber-stamped. Money needs to spend on investigations rather than damage control and the NHBRC should therefore send the message to investigators and developers that if they want their townships approved, they need to do the work, and do it properly.

### 6.5.2 Investigations for Piles and Lateral Support

Although the geotechnical investigation requirements established for piled foundations and lateral support are satisfactory, failures relating to such investigations still occur due to non-compliance with these requirements. The presented case study clearly demonstrates non-compliance with existing requirements, not only by the geotechnical profession, but by the client and the project management team as well.

The engineering profession is regulated by the Engineering Council of South Africa (ECSA) that primarily provides accreditation for professionalism and controls the practice of registered persons thereby, enforcing compliance with established norms. However, as a result of recent rulings by the Competitions Commission, the Engineering Council is unable to enforce Section 26 (3) of the Act which prohibits persons who are not registered with the Council from undertaking engineering work. The Council is powerless to act against such persons. The solution to this problem lies in the hands of the client who can specify that geotechnical investigations must be carried out by registered persons and in accordance with specified standards. This is a “demand side” requirement imposed by the client / developer as opposed to a “supply-side” requirement imposed by the Engineering Council.

However, two particular concerns arise from the aforementioned. Firstly, this assumes that developers, clients and project managers have sufficient knowledge and understanding of site investigation practices to correctly specify the geotechnical investigation requirements. This is sadly not the case. The profession therefore need provide developers, clients and project managers with the necessary specifications (technical knowledge) to adequately specify the scope of geotechnical investigations to be provided. Although there are no regulatory requirements which can force developers and clients to comply, making it easier to adequately specify minimum requirements for various categories of development could go a long way to addressing the problem.

### 6.5.3 General recommendations

In the introduction to this chapter, it was stated that we may need to look beyond compliance with geotechnical investigation requirements to find a lasting solution to the problem. The general recommendations below are therefore not aimed at enforcing compliance but at making it easier to achieve compliance by modifying procurement practices.

The entire approach to procuring geotechnical investigations has changed. Typically, such procurement is undertaken by the by the client, the structural engineer, the quantity surveyor or the project manager who do not necessarily have the technical knowledge to specify the scope of the investigation or adjudicate the adequacy of tenders received for site investigation contracts.

In the past, procurement of geotechnical investigations was normally the responsibility of the lead designer or the client's engineering team, who usually contacted respected/trusted geotechnical engineers and invited them to submit proposals. The scope of the work was therefore decided by the geotechnical specialist.

These days, corporate governance requires that such services go out to tender. Often this is done without any specification of the scope of the investigation, the professional status of the investigator or the standards to be followed. Thus, anybody who has some sort of equipment and considers themselves eligible can put in a tender for investigations. The person adjudicating the tender is in most instances, a government official or project manager, who does not necessarily have the technical knowledge to be able to judge the technical merits of the tenders received and the decision is often based on price alone. The result is that people who are not technically equipped to do site investigations are submitting cost proposals for non-compliant investigations to people who don't have the required knowledge to adjudicate these proposals.

This raise the question of whether other fields of engineering are faced with the same problems and have they found a solution? If we look to the civil engineering profession in general, this indeed so.

For most other fields of engineering, the relevant requirements are laid down in standardised specification such as SANS 1200 for civil engineering works in general or the COLTO Specification for road and bridge construction. With these documents at their disposal, it is not necessary for the person compiling the specification and tender document to have detailed knowledge of civil engineering works or the construction of roads and bridges. They can, and in most cases, do, simply include these standardised specifications by reference in the contract document. This goes a long way towards insuring comparable bids are received and that the work is correctly undertaken.

Unfortunately, there are currently no standardised specifications similar to SABS 1200 for geotechnical investigations. The requirements exist as set out in Chapters 3 and 4 but are not presented in the form that makes it simple for non-geotechnical professionals to easily specify geotechnical investigations. It is therefore recommended that the geotechnical profession should compile a set of standardised specifications similar to SABS 1200 for various types of structures and developments.

Given that the above proposal may take time to implement, short-term mitigation measures are:

- ✓ Ensure that all relevant information, including township investigation reports are made available the developer of individual stands and their appointed competent person.
- ✓ Publish geotechnical failures. The greater the data available, the more aware investigators, clients and developers will be. Also, the geotechnical profession will then be able to get to a stage where they know where problem areas ("red-zones") are and the nature of the problems that can potentially arise.
- ✓ Geo-professionals should be asked to report on pitfalls in requirements and make suggestions for change. Codes and Standards needs to be revised at least every 5 years to incorporate such recommendations. These are, after all, the people who are involved in site investigations every day.
- ✓ Once all the standardised specifications for various types of developments have been compiled and accepted by the geotechnical profession, a concerted effort should be made to publicise these standards, demonstrate the benefits of their application and encourage their use.
- ✓ Continue to develop sinkhole database on dolomites.
- ✓ Compile a standard or code of practice for slope investigations, specifically dealing with investigations on slopes along coastal areas (see section 6.8 for future research suggestions).

A summary of the recommendations to improve the success and quality of, and minimize geotechnical failures are given in Figure 6.1.


*Figure 6.1: A summary of the recommendations presented in the research.*

## 6.6 Example of Standardised Specifications

In addition to the specific objective set out in section 1.4 (iv), the compilation of standardised specifications for geotechnical investigations for various types of development was also recommended in section 6.5.3 above. To illustrate the form such documents could take, a draft of standardised specifications for investigation of residential townships and housing, investigation of excavations and lateral support and investigations for pile foundations has been developed. These draft specifications are presented in Appendix D1, Appendix D2 and Appendix D3 respectively.

It should be noted that this draft is aimed at remedying the observed inadequacies in such investigations as set out in Chapter 5. For township and housing development in particular, this document seeks to ensure, following the township investigation report, the additional investigation to undertaken on each individual stand is affordable.

These standardised specifications does not replace existing standards. However, it requires compliance with such standards which would otherwise have been voluntary.

Part 2 of the specification contains the essential project data that is to be provided to make the specification relevant to a particular development. This is similar to the approach adopted in SABS 1200.

## 6.7 Overall Conclusion

Adequate geotechnical investigations form the basis for successful construction projects. Uncertainty of geological and ground conditions below earth's surface leaves no construction project free of risk. The intention is that such risks should be identified and mitigated by way of geotechnical investigations carried out in accordance with relevant legislation and the norms of the industry.

Although various innovative approaches have been adopted over the years, the geotechnical regulatory framework still lack efficiency, coherence, enforceability and control.

This research has explored factors leading to geotechnical failures on small and large civil engineering projects due to inadequate investigation and suggests that more control be exercised over the geotechnical investigations to ensure compliance with the existing regulatory framework. In most instances, the available regulations, standards and codes of practice are adequate, but are not followed. It is a case of knowing what is required but not doing it.

Case studies presented in the research show that the responsibility for the adequacy of the investigation rests not only with the geo-professional but is shared with clients, contractors, regulatory bodies and local authorities. Geotechnical failures are not always due to non-compliance of geo-professionals and they are therefore not the only group of people that should be held responsible for these failures. The industry focuses on the responsibilities of geo-professionals, but fails to notice and act upon non-compliance by developers, clients, regulators and local authorities.

Two of the factors that contribute to the inadequacy geotechnical investigations are cost and programme. These factors often override the norms established for responsible geotechnical investigations. Developers and their project teams often fail to realise that savings on the time and cost of an investigation are insignificant when compared to the claims and programme extensions that can result during construction if the geotechnical conditions are not adequately investigated. The responsibility needs to be shifted back to the persons that are gaining financially from these developments.

The traditional procurement process for geotechnical investigations based on invited proposals from geotechnical specialists has been replaced by tendering for geotechnical work, often on the basis of no or inadequate specifications. Such tenders are difficult to adjudicate by persons who lack a fundamental understanding of geotechnical investigations and the award is often based on price rather than the adequacy of the scope of work offered. Thorough understanding of requirements and preparation of an adequate contract are vital steps in minimising this risk as well as cost and schedule overruns.

This study therefore expresses the need for changes that support efficient and successful implementation of the regulatory framework for geotechnical investigations.

## 6.8 Future Research

Future research may include the development of further standardised specifications for various types of development. Consideration may also be given to developing codes of practice for geotechnical investigations of expansive soils and of slopes, both of which are seen to be problematic. The motivation for such codes is the widespread distribution of expansive soils in South Africa and the observation that development on slopes is a general occurrence particularly in coastal areas. The fact that the South African National Roads Agency Limited (SANRAL) recently started monitoring of slopes along the national roads in most provinces will assist greatly in gathering valuable data for slope stability analysis. The study can therefore identify problem areas and similar to that used in the development of dolomite areas by assigning inherent hazard ratings to sloping ground.

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# Appendices

# Appendix A
# Geo-professional's Conduct

# Appendix A1
# ECSA Code of Conduct

**BOARD NOTICE 41 OF 2017**

**ENGINEERING COUNCIL OF SOUTH AFRICA**

ECSA

# Code of Conduct for Registered Persons: Engineering Profession Act, 2000 (Act No. 46 of 2000)

The Engineering Council of South Africa hereby, in terms of section 36 of the Engineering Profession Act, (Act No. 46 of 2000), makes known that it has under section 27 of that Act, made the rules in the Schedule.

## SCHEDULE

### 1. Objectives

The objectives of this Schedule are to ensure that Registered Persons, in the execution of their engineering work -

1.1 apply their knowledge and skill in the interests of the public and the environment;

1.2 execute their work with integrity and in accordance with generally accepted norms of professional conduct;

1.3 respect the interests of the public and honour the standing of the profession;

1.4 strive to improve their professional skills and those of their subordinates;

1.5 encourage excellence within the engineering profession; and

1.6 do not prejudice public health and safety.

## 2. Definitions

In this Schedule any expression or word that has been defined in the Act has that meaning, and unless the context otherwise indicates -

2.1 **"business undertaking"** means any business enterprise or entity, joint venture, consortium, association or any such organisation or entity;

2.2 **"Council"** means Engineering Council of South Africa established by section 2 of the Act;

2.3 **"engineering work"** means the process of applying engineering and scientific principles, concepts, contextual and engineering knowledge to the research, planning, design, implementation and management of work in both the natural and built environments;

2.4 **"information"**; means engineering documents and data produced or relied upon by the Registered Person in the performance of work that form a material part of the project records, including competent person or similar appointments, design calculation drawings and inspection certificates, whether electronic format or otherwise.

2.5 **"Registered Persons"** means persons registered in terms of the Act;

2.6 **"the Act"** means the Engineering Profession Act, 2000 (Act No. 46 of 2000); and

2.7 **"work"** means any engineering work normally carried out by Registered Persons in the practice of their profession.

## 3. Rules of Conduct: Ethics

Registered Persons in fulfilling the objectives contemplated in clause 1 above must comply with the following rules:

### 3.1 Competency

**Registered Persons: -**

(a) must discharge their duties to their employers, clients, associates and the public with due care, skill and diligence.

(b) may only undertake work which their education, training and experience have rendered them competent to perform and is within the category of their registration.

(c) must, when carrying out work, adhere to norms of the profession.

## 3.2 Integrity

**Registered Persons: -**

(a) must discharge their duties to their employers, clients, associates and the public with integrity, fidelity and honesty;

(b) must not undertake work under conditions or terms that would compromise their ability to carry out their responsibilities in accordance with the norms of the profession;

(c) must not engage in any act of dishonesty, corruption or bribery;

(d) must disclose to their employers and clients, or prospective employers or clients, in writing: -

(i) any interest, whether financial or otherwise, which they may have in any business undertaking or with any person, and which is related to the work for which they may be or have been employed;

(ii) particulars of any royalty or other benefit which accrues or may accrue to them as a result of the work performed for; the client or employer concerned; and

(iii) the status of their professional indemnity insurance cover, upon request;

(e) may not, either directly or indirectly, receive any gratuity, commission or other financial benefit for any article or process used in, or for the purpose of, the work for which they are employed, unless such gratuity, commission or other financial benefit has been disclosed in writing to the employer or client concerned;

(f) must avoid situations that give rise to a conflict of interest or the potential for such conflict of interest;

(g) may not misrepresent, or knowingly permit misrepresentation of their own or any other person's academic or professional qualifications or competency, nor exaggerate their degree of responsibility for any work;

(h) must give engineering decisions, recommendations or opinions that are honest, objective and based on facts;

(i) may neither personally nor through any other person, improperly seek to obtain work, or by way of commission or otherwise, make or offer to make payment to a client or prospective client for obtaining such work;

(j) must ensure that any work approved or certified by them, has been reviewed or inspected to the extent necessary to confirm the correctness of the approval or certification;

(k) may not, unless required by law or by these Rules, divulge any information of a confidential nature which they obtained in the exercise of their duties;

(l) must notify Council on becoming insolvent where such insolvency is caused by his or her negligence or incompetence in performing engineering work;

(m) must, without delay, notify Council if they become subject to one or more of the following:

(i) removal from an office of trust on account of improper conduct;
(ii) being convicted of an offence and sentenced to imprisonment without an option of a fine, or, in the case of fraud, to a fine or imprisonment or both.

## 3.3 Public Interest

**Registered Persons: -**

(a) must at all times have due regard for and give priority to the health, safety and interest of the public.

(b) must when providing professional advice to a client or employer, and such advice is not accepted, inform such client or employer of any consequences which may be detrimental to the health, safety or interests of the public and at the same time inform the Council of their action.

## 3.4 Environment

**Registered Persons must at all times -**

(a) have due regard for, and in their work avoid or minimise, adverse impact on the environment; and

(b) strive to ensure that in meeting present development needs, the ability of future generations to meet their needs is not compromised,

## 3.5 Dignity of the Profession

**Registered Persons: -**

(a) must order their conduct so as to uphold the dignity, standing and reputation of the profession;

(b) may not maliciously or falsely, whether in the practice of their profession or otherwise, knowingly injure the professional reputation or business of any other Registered Person or the reputation of the Council;

(c) may not improperly supplant or attempt to supplant a Registered Person in a particular engagement after such Registered Person has been employed;

(d) may not advertise their professional services in a misleading or exaggerated manner or in a manner that is harmful to the dignity of the profession;

(e) may not review the work carried out for a particular client by another Registered Person, except -

(i) where the review is carried out for a different client; or
(ii) with the prior knowledge of the other Registered Person; or
(iii) after receipt of a notification in writing from the client that the engagement of the other Registered Person has been terminated; or
(iv) where the review is intended for purposes of dispute resolution or legal proceedings, including proceedings arising from these Rules; or
(v) for routine or statutory checks.

## 4. Administrative

**Registered Persons: -**

(a) may not without satisfactory reasons destroy or dispose of, or knowingly allow any other person to destroy or dispose of, any information within a period of 10 years after completion of the work concerned;

(b) may not place contracts or orders, or be the medium of payments, on their employer's or client's behalf without the written authority of the employers or clients;

(c) may not issue any information prepared by them or by any other person under their direction or control, unless this information bears -

(i) the name of the organisation concerned;
(ii) the name of the Registered Person concerned or another appropriately qualified and authorised person; and
(iii) the date of preparation.

(d) may, in instances where the signature of a Registered Person is required, use an electronic signature as defined in the Electronic Communications and Transactions Act, 2002 (Act No. 25 of 2002);

(e) must order their conduct in connection with work outside the borders of the Republic of South Africa in accordance with these rules in so far as they are not inconsistent with the law of the country concerned: Provided that where there are recognised standards of professional conduct in a country outside the Republic, they must adhere to those standards in as far as they are not inconsistent with these rules.

(f) must supervise, and take responsibility for, work carried out by their subordinates including persons registered as candidates;

(g) must ensure that, while engaged as partners, directors, members or employees of a business undertaking which performs work, the control over the work is exercised, and the responsibility in respect thereof is carried out by a Registered

Person other than a person registered as a candidate in terms of section 18 (1)(b) of the Act;

(h) must, when requested by the Council to do so, in writing provide the Council with all the information available to them which may enable the Council to determine which Registered Person was responsible for any act that the Council may consider ***prima facie*** to be improper conduct;

(i) must notify Council without delay of any change of his or her physical address;

(j) must within 30 days respond to correspondence received from clients, colleagues and Council in so far as it relates to work or proceedings in terms of these Rules.

## 5. Repeal of Rules

The rules published in Board Notice 256 of 2013 are hereby repealed, subject to section 12(2) of the Interpretation Act, 1957 (Act No. 33 of 1957).

## 6. Short title

This Schedule is called the Code of Conduct for Registered Persons.

# Appendix A2
# SACNASP Code of Conduct

SACNASP

South African Council for Natural Scientific Professions

# Code of Conduct

The Council has drawn up the following Code of Conduct with which registered persons must comply. Failure to do so constitutes improper conduct.

In practising their professions, Certificated, Candidate and Professional Natural Scientists must:

1. Have due regard to public safety, public health and public interest generally.
2. Have due regard to harmful practices against the environment.
3. Discharge their duties to their respective employers or clients efficiently and with integrity.
4. Conduct themselves in such a way as to uphold the dignity, standing and reputation of the natural scientific professions.
5. Not undertake natural scientific work for which their education, experience or background have not rendered them competent to perform.
6. Disclose to their respective employers or clients in writing:
   (a) any interest which they may have in any company, firm or organisation, or with any person, and which is related to the work for which they may be or may have been employed; and
   (b) particulars of any royalty or other financial benefit which accrues or may accrue to them as a result of such work.
7. Not deliberately injure directly or indirectly, the professional reputation, prospects or business of another registered person.
8. Not knowingly attempt to supplant another registered person after a formal offer of employment has been made.
9. Not advertise their professional services in a self-laudatory manner or in a manner that is derogatory to the dignity of the profession.
10. Not knowingly misrepresent or permit misrepresentation of their own or their associates' academic or professional qualifications, nor exaggerate their own degree of responsibility for any work of a natural scientific nature.
11. Not, without a satisfactory reason, destroy calculations, documentary or any other evidence required for the verification of their work.
12. Not personally, or through any other agency, attempt to obtain consulting work by way of touting or bribery.
13. Order their conduct when practising their professions in another country in accordance with these rules in so far as they are not inconsistent with the law of the country concerned; provided that they shall also adhere to the standards of professional conduct in that country.

# Appendix B
# Classification of Road Materials

# Appendix B1
# COLTO:1998 Specification

Relevant tables extracted from COLTO:1998 Specification and compiled as given, by Matrolab Group (Pty) Ltd South Africa.

Obtained from https://www.matrolab.co.za/files/content/docs/colto-specifications_2009.pdf

# COLTO SPECIFICATIONS - MARCH 1998

Review 27 November 2017

| PROPERTY | G1 | G2 | G3 | G4 | G5 | G6 | G7 | G8 | G9 |
|---|---|---|---|---|---|---|---|---|---|
| **DESRIPTION OF MATERIAL** | Sound rock from an approved quarry, or clean, sound mine rock from mine dumps, or clean sound boulders | Sound rock, boulders or coarse gravel | | Natural gravel, or natural gravel & boulders which may need crushing | Natural gravel, or natural gravel & boulders which may need crushing or crushed rock | Natural gravel, or natural gravel & boulders which may need crushing or crushed rock | Natural material (soil, sand or gravel) | Natural material (soil, sand or gravel) | Natural material (soil, sand or gravel) |
| **ADDITIONAL FINES** | Only fines crushed from the same sound parent rock may be added for grading correction provided that added fines shall have a LL not exceeding 25 and PI not exceeding 4 | May contain up to 10% by mass of approved natural fines not necessarily obtained from parent rock. Added fines shall have a LL not exceeding 25 and PI not exceeding 6 | May contain up to 15% by mass of approved natural fines not obtained from parent rock. Added fines shall have a LL not exceeding 25 and PI not exceeding 6 | May contain approved additional fines not obtained from parent rock. Added fines shall have a liquid limit not exceeding 25 and a plasticity index not exceeding 6 | May contain approved natural fines not obtained from parent rock. | May contain approved natural fines not obtained from parent rock. | - | - | - |
| **NOMINAL MAXIMUM SIZE** | 37.5mm | 37.5mm | 37.5mm / 26.5mm | Uncrushed 53mm : crushed 37.5 or 26.5mm | Uncrushed 63mm : crushed 53mm before compaction | Uncrushed : 2/3 compacted layer : crushed 63mm before compaction | Uncrushed : 2/3 compacted layer crushed material: 75mm | 2/3 compacted layer | 2/3 compacted layer |
| **FLAKINESS INDEX** | Flakiness Index, determined in accordance with TMH1 method B3, shall not exceed 35 on each of the -26.5+19mm fraction and the -19+13.2mm fraction | | | As per TMH1 B3 shall not exceed 35 on each of the -26.5+19mm fraction and - 19+13.2mm fraction | - | - | - | - | - |
| **FRACTURED FACES** | All faces shall be fractured faces | For crushed materials at least 50% by mass of the fractions retained on each standard sieve 4.75mm and larger shall have at least one fractured face. | | Alluvial & colluvial gravels shall be crushed so that at least 50% by mass of the fractions retained on each standard sieve 4.75mm and larger shall have at least one fractured face | Alluvial & colluvial material shall be crushed so that at least 50% by mass of the fractions retained on 4.75mm shall have at least on fractured face | - | - | - | - |
| **GRADING** | * see reverse | * see reverse | * see reverse | * see reverse | * see reverse | - | - | - | - |
| **GRADING MODULUS** | - | - | - | - | 2.5 ≥ GM ≥ 1.5 | 2.6 ≥ GM ≥ 1.2 | 2.7 ≥ GM ≥ 0.75 | 2.7 ≥ GM ≥ 0.75 | 2.7 ≥ GM ≥ 0.75 |
| **ATTERBERG LIMTS (-0.425mm FRACTION)** | LL shall not exceed 25 PI shall not exceed 5 LS shall not exceed 2% In addition the arithmetic mean of the PI's for a lot (min 6 tests) shall not exceed 4 | LL shall not exceed 25 PI shall not exceed 6 LS shall not exceed 3% In addition the arithmetic mean of the PI's for a lot (min 6 tests) shall not exceed 4.5 | LL shall not exceed 25 PI shall not exceed 6 LS shall not exceed 3% In the case of calcrete the PI shall not exceed 8. (% passing 0.425mm sieve) LS ≤ 170 | a) **All materials except calcrete** LL shall not exceed 25 PI shall not exceed 6 LS shall not exceed 3% **b) Calcrete** LL ≤ 25 PI ≤ 8 (% passing 0.425mm sieve ) LS ≤ 170 | a) **All materials except calcrete** LL shall not exceed 30 PI shall not exceed 10 LS shall not exceed 5% **b) Calcrete** LL ≤ 30 PI ≤ 15 LS ≤ 6 (% passing 0.425mm sieve ) LS ≤ 320 | PI shall not exceed 12 or a value equal to 2 times the GM plus 10, whichever is the higher value. LS shall not exceed 5%. In the case of calcrete the PI shall not exceed 15 provided the LS does not exceed 6% and (% passing 0.425mm sieve) LS ≤ 320 | The PI shall not exceed 12 or a value equal to 3 times the GM plus 10, whichever is the higher value. In the case of calcrete the PI shall not exceed 17 provided that the LS does not exceed 7% and (% passing 0.425mm sieve) LS ≤ 320 | The PI shall not exceed 12 or a value equal to 3 times the GM plus 10, whichever is the higher value. In the case of calcrete the PI shall not exceed 17 provided that the LS does not exceed 7% | The PI shall not exceed 12 or a value equal to 3 times the GM plus 10, whichever is the higher value. In the case of calcrete the PI shall not exceed 17 provided that the LS does not exceed 7% |
| **ATTERBERG LIMTS (-0.075mm FRACTION)** | The PI shall not exceed 12. If the PI exceeds 12 the material shall be chemically modified. After chemical modification the PI of the minus 0.075mm fraction shall not exceed 8. | | If chemical modification is required, the PI of the 0.075mm fraction after modification shall not exceed 10 | - | - | - | - | - | - |
| **DURABILITY** | The material shall comply with the requirements in columns 3, 4 and 5 of table 3602/2 (COLTO) | | | The material shall comply with the requirements in table 3402/3 (COLTO) | Mudrock shall have a wet 10% FACT value of not less than 90 kN, and a wet/dry Venter test class of I or II | Mudrock shall have a wet 10% FACT value of not less than 80 kN, and a wet/dry Venter test class of I or II | Mudrock shall have a wet 10% FACT value of not less than 60 kN, and a wet/dry Venter test class of I , II or III | Mudrock shall have a wet 10% FACT value of not less than 60 kN, and a wet/dry Venter test class of I , II or III | Mudrock shall have a wet 10% FACT value of not less than 60 kN, and a wet/dry Venter test |
| **SOLUBLE SALTS** | See additional requirements (COLTO) | | | The material shall comply with the requirements in clause 3602 (COLTO) | | | | | |
| **STRENGTH (CBR)** | - | - | - | CBR at 98% of modified AASHTO denisty shall not be less than 80% | CBR at 95% of modified AASHTO density shall not be less than 45% | CBR at 95% of modified AASHTO density shall not be less than 25% | CBR at 93% of modified AASHTO density shall be at least 15% | CBR at 93% of modified AASHTO density shall be at least 10% | CBR at 93% of modified AASHTO density shall be at least 7% |
| **SWELL (MAXIMUM)** | - | - | - | Swell at 100% modified AASHTO density shall not exceed 0.2% for all materials except calcrete for which the swell shall not exceed 0.5% | Swell at 100% modified AASHTO density shall not exceed 0.5% | Swell at 100% modified AASHTO density shall not exceed 1.0% | Swell at 100% modified AASHTO density shall not exceed 1.5% | Swell at 100% modified AASHTO density shall not exceed 1.5% | Swell at 100% modified AASHTO density shall not exceed 1.5% |
| **COMPACTION REQUIREMENTS** | Minimum 0f 88% of apparent relative density | Minimum of 85% of bulk relative denity | 98% or 100% of modified AASHTO density (as specified) | 98% or 100% (as specified) of modified AASHTO density for natural materials | The density requirements of the layer in which the material is used, shall be applicable. (See subclause 3402(b)(COLTO) In restricted areas the in situ dry density of gravel material shall comply wuth the requirements in the project specifications. | | | | |
| **Strength** | 10% fines aggregate crushing value (10% FACT), determined in accordance with TMH1 method B2, shall be not less than the appropriate value in table 3602/2, column 3. The Aggregate Crushed Value (ACV), determined in accordance with TMH1 method B1, shall not exceed the appropriate value in table 3602/3. | | | | | | | | |
| **COARSE SAND RATIO (SEE DEFINITION IN SUBCLAUSE 3602( c)(i)(5))** | Shall not be less than 35% and shall not exceed 50% in respect of the target grading | Shall not be less than 35% and shall not exceed 50% in respect of the target grading | Shall not be less than 35% and shall not exceed 50% in respect of the target grading | | | | | | |

## GRADING OF GRADED CRUSHED STONE

| GRADING: NOMINAL APERTURE SIZE OF SIEVE (mm) | G1: PERCENTAGE PASSING SIEVE BY MASS | G2: PERCENTAGE PASSING SIEVE BY MASS | G3: PERCENTAGE PASSING SIEVE BY MASS | | G4: PERCENTAGE PASSING SIEVE BY MASS | | | G5 |
|---|---|---|---|---|---|---|---|---|
| | | | | | CRUSHED | | UNCRUSHED | |
| | 37.5mm | 37.5mm | 37.5mm | 26.5mm | 37.5mm | 26.5mm | | |
| 53.0 | | | | | | | 100 | The percentage by mass passing the 2.00mm sieve shall not be less than 20% nor more than 70% |
| 37.5 | 100 | 100 | 100 | | 100 | | 85 - 100 | |
| 26.5 | 84 - 94 | 84 - 94 | 84 - 94 | 100 | 84 - 94 | 100 | - | |
| 19.0 | 71 - 84 | 71 - 84 | 71 - 84 | 85 -95 | 71 - 84 | 85 -95 | 60 - 90 | |
| 13.2 | 59 - 75 | 59 - 75 | 59 - 75 | 71 - 84 | 59 - 75 | 71 - 84 | - | |
| 4.75 | 36 - 53 | 36 - 53 | 36 - 53 | 42 - 60 | 36 - 53 | 42 - 60 | 30 - 65 | |
| 2.00 | 23 - 40 | 23 - 40 | 23 - 40 | 27 - 45 | 23 - 40 | 27 - 45 | 20 - 50 | |
| 0.425 | 11 - 24 | 11 - 24 | 11 - 24 | 13 - 27 | 11 - 24 | 13 - 27 | 10 - 30 | |
| 0.075 | 4 - 12 | 4 - 12 | 4 - 12 | 5 - 12 | 4 - 12 | 5 - 12 | 5 - 15 | |

## 10% FINES AGGREGATE CRUSHING VALUES (Table 3602/2)

| Rock Type | Matrix | Dry (min.) | Wet (min.) | Wet / Dry (min.) |
|---|---|---|---|---|
| Arenaceous rocks | Non-siliceous cementing material | 140kN | | 75% |
| | Siliceous cementing material | 110kN | | 75% |
| Diamictites (tillites) | | 200kN | | 70% |
| Argillaceous rocks | | 180kN | 125kN | - |
| Other rock types | | 110kN | | 75% |

## DURABILITY REQUIREMENTS FOR G4 MATERIAL (Table 3402/3)

| GROUP | MEMBERS OF GROUP | DURABILITY MILL INDEX (MAX.) | % PASSING 0.425mm SIEVE AFTER DURABILITY MILL TEST (MAX.) |
|---|---|---|---|
| Basic crystaline rock | Basalt<br>Dolerite<br>Gabbro | 125 | 35 |
| Acid crustaline rock | Gneiss<br>Granite | 420 | 35 |
| High silica rock | Chert<br>Hornfels<br>Quartzite | 420<br>(clay mineral kaolin) | 35 |
| Sandstone | Arkose<br>Conglomerate<br>Sandstone<br>Siltstone | 125 | 35<br>(increase from original not more than 15%) |
| Mudrock | Mudrock<br>Phylite<br>Shale etc | 125 | 35 |
| Carbonate rock | Dolemite<br>Limestone<br>Marble | not applicable | not applicable |
| Diamictities | Greywacke<br>Tillite | 125 | 35 |
| Pedogenic material | Calcrete<br>Ferricrete<br>Silcrete | 480 | 40 |

## AGGREGATE CRUSHING VALUE (Table 3602/3)

| Rock Type | ACV, max. |
|---|---|
| Arenaceous: without siliceous cementing matrix | 27% |
| Arenaceous: with siliceous cementing matrix | 29% |
| Diamictites (tillites) | 21% |
| Argillaceous rocks | 24% |
| Other rock types | 29% |

*for more detailed information and interpretations see latest COLTO*

MATROLAB

# Appendix B2
# COLTO:1998 Specification

A summary of TRH14 classification system for granular materials, gravels and soils as given in the South African Pavement Engineering Manual, Chapter 4 (SAPEM, 2013).

Obtained from
http://www.nra.co.za/content/SAPEM_Chapter_4_Jan2013.pdf

## Summary of TRH14 Classification System for Granular Materials, Gravels and Soils

Notes

| Groups | G1, G2, G3: Graded Crushed Stone | | | G4, G5, G6: Natural Gravels | | | G7, G8, G9, G10: Gravel Soil | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Description** | G1 Crushed unweathered rock | G2, G3 Crushed rock, boulders or coarse gravel | | Natural gravel; may be mixed with crushed rock such as boulders. May be cementitiously or mechanically modified. | | | Categorised in terms of properties below. | | | |
| **Material Class** | **G1** | **G2** | **G3** | **G4** | **G5** | **G6** | **G7** | **G8** | **G9** | **G10** |
| **GRADING** | | | | | | | | | | |
| **Sieve Size (mm)** | Nominal max size 37.5 mm[1] | Nominal max size **28** (26.5) mm[1] | | | Max size 64 mm or two-thirds of compacted layer thickness, whichever is smaller. | | Max size, in place, after compaction, shall not be greater than two-thirds of the layer thickness. | No grading requirements | | |
| 50 / 53 | 100 | | | 100 | | | | | | |
| 37.5 | 100 | | | 85 – 100 | | | | | | |
| 28 / 26.5 | 84 – 94 | 100 | | – | | | | | | |
| 20 / 19 | 71 – 84 | 85 – 95 | | 60 – 90 | | | | | | |
| 14 / 13.2 | 59 – 75 | 71 – 84 | | – | | | | | | |
| 5 / 4.75 | 36 – 53 | 42 – 60 | | 30 – 65 | | | | | | |
| 2 | 23 – 40 | 27 – 45 | | 20 – 50 | | | | | | |
| 0.425 | 11 – 24 | 13 – 27 | | 10 – 30 | | | | | | |
| 0.075 | 4 – 12 | 5 – 12 | | 5 – 15 | | | | | | |
| **Grading Modulus (min)** | n/a | | | n/a | 1.5 | 1.2 | n/a | | | |
| **Flakiness Index** | Max 35% on weighted average of -28 (26.5) and -20 (19) mm fractions | | n/a | n/a | | | n/a | | | |
| **Crushing Strength** | 10% FACT (min) 110 kN or ACV (max) 29% | | n/a | n/a | | | n/a | | | |
| **ATTERBERG LIMITS** | | | | | | | | | | |
| **Liquid Limit (max)** | 25 | 25 | | 25 | 30 | n/a | n/a | No Atterberg Limit requirements | | |
| **Plasticity Index, PI (max)** | 4 | 6 | | 6 | 10 | 12 or 3 GM[2] + 10 | 12 or 3 GM[2] + 10 | | | |
| **Linear shrinkage, % (max)** | 4 | 3 | | 3 | 5 | n/a | n/a | | | |
| **Linear shrinkage x -0.425 mm sieve (max)**[3] | n/a | | | 170 | 170 | n/a | n/a | | | |
| **BEARING STRENGTH AND SWELL** | | | | | | | | | | |
| **CBR,** % (min) at MDD[4] | n/a | 80 at 98% | | 80 at 98% | 45 at 95%[5] | 25 at 93% | 15 at 93% | 10 at in situ | 7 at in situ | 3 at in situ |
| **Swell,** % (max) at MDD | n/a | 0.2 at 100% | | 0.2 at 100% | 0.5 at 100% | 1.0% | 1.5% | | | |
| **Material Class** | **G1** | **G2** | **G3** | **G4** | **G5** | **G6** | **G7** | **G8** | **G9** | **G10** |

Notes:

1. G1 adjustments to the grading can only be made using crusher dust or other fractions from the parent rock. Only in exceptional cases can a maximum 10% non-plastic fines be added. G2 and G3 materials may be a blend of crushed stone and other fine aggregate to adjust the grading.
2. GM is the grading modulus (see Chapter 3, Section 2.3.2)
3. Only applicable to nodular calcretes
4. MDD is the maximum dry density determined by the modified AASHTO method.
5. In dry areas (Weinert N > 10) and AADT < 300 vpd CBR can be reduced to 25% @ 95% MDD if subbase cover is at least 150 mm.

# Appendix B3
# SABS 1200M:1996 Classification

# TABLE 3A AND 3B OF SANS 1200M:1996

| CRITERIA | G1 | G2 | G3 | G4 | G5 | G6 | G7 |
|---|---|---|---|---|---|---|---|
| PARENT MATERIAL | Sound rock from an approved quarry, or clean, sound mine rock from mine dumps, or clean sound boulders | Sound rock, boulders or coarse gravel | Sound rock, boulders or coarse gravel | Natural gravel or natural gravel and boulders which may require crushing | Natural gravel or natural gravel and boulders which may require crushing, or crushed rock | Natural gravel or natural gravel and boulders which may require crushing, or crushed rock | Natural material |
| ADDITIONAL FINES | Only fines crushed from the same sound parent rock may be added for grading correction, provided that added fines have an LL not exceeding 25 and a PI not exceeding 4 | May contain up to 10% (by mass) of approved natural fines not obtained from parent rock, where required to improve grading. Added fines shall have an LL not exceeding 25 and a PI not exceeding 6 | May contain up to 15 % (by mass) of approved natural fines not obtained from parent rock, where required to improve grading or Atterberg limits or both. Added fines shall have an LL not exceeding 25 and a PI not | May contain approved natural fines not obtained from parent rock. Added fines shall have an LL not exceeding 25 and a PI not exceeding 6 | May contain approved natural fines not obtained from parent rock | May contain approved natural fines not obtained from parent rock | nrp |
| STRENGHT | 10 % fines aggregate crushing value (10 % FACT), determined in accordance with BABS method 842 (TMH 1 method B2), shall be at least the appropriate value in column 3 of table 4. The aggregate crushing value (ACV), determined in accordance with SABS method 841 (TMH 1 method B1), shall not exceed the appropriate value in table 5. | | | CBR at 98 % Mod. AASHTO max. density shall be at least 80 %. Swell at 100 % Mod. AASHTO max. density shall not exceed 0.2% for all materials except | CBR at 95 % of Mod. AASHTO max. density shall be at least 45 %. Swell at 100 % of Mod. AASHTO max. density shall not exceed 0,5 %. | CBR at 95 % of Mod. AASHTO max. density shall be at least 25 %. Swell at 100 %. of Mod. AASHTO max. density shall not exceed 1,0%. | CBR at 93 % of Mod. AASHTO max. density shall be at least 15 %. Swell at 100 % of Mod. AASHTO max. density shall not exceed 1,5 %. |
| DURABILITY | See columns 3, 4 and 5 of table 4 | | | See table 5 | Mudrocks shall have a wet 10 % FACT value of at least 90 kN and a wet/dry Venter test class7) of I or II. | Mudrocks shall have a wet 10 % FACT value of at least 80 kN and a wet/dry Venter test class7) of I or II. | Mudrocks shall have a wet 10 % FACT value of at least 60 kN and a wet/dry Venter test class7) of I, II or III. |
| SHAPE | The flakiness index, determined in accordance with BABS 847 (TMH 1 method B3T), shall not exceed 35 on each of the -26,5 mm +19 mm fraction and the -19 mm +13,2 mm fraction | | | Alluvial and colluvial gravels shall be crushed | All alluvial or colluvial material shall be so crushed that at least (50 % by mass) of the fraction retained on the 4,75mm sieve has at least one fractured face | nrp5) | |
| | All faces shall be fractured faces | For crushed materials, at least 50 o/. (by mass) of the fractions retained on each standard sieve of 4,75 mm and larger shall have at least one fractured face | | | | | |
| ATTERBERG LIMTS | LL shall not exceed 25. Except that the arithmetic mean of the results for a lot (min. 6 tests) shall not exceed 4, the PI shall not exceed 5. LS shall not exceed 2 %. If the PI of the minus 0,075 mm fraction exceeds 12, see 3.3.6. | LL shall not exceed 25. Except that the arithmetic mean of the results for a lot (min. 6 tests) shall not exceed 4,5, the PI shall not exceed 6. LS shall not exceed 3%. If the PI of the minus 0,075 mm fraction exceeds 12, see 3.3.6. | LL shall not exceed 25. PI shall not exceed 6, except in the case of calcretes, in which case it shall not exceed 8. LS shall not exceed 3 %. | LL shall not exceed 25. PI shall not exceed 6, except in the case of calcretes, in which case it shall not exceed 8. LS shall not exceed 3 %. For calcretes the product of LS and the percentage passing a 0,425mm sieve shall not exceed 170. | LL shall not exceed 30. PI shall not exceed 10, except that for materials other than mudrocks, the PI shall not exceed 12 if less than 30 % of the sample passes the 2,00mm sieve. LS shall not exceed 5 %. In the case of calcretes, the PI shall not exceed 15, provided that the LS does not exceed 6 % and the product of the LS and the percentage passing the 0,425mm sieve does not exceed 320. | PI shall not exceed 12 or the value equal to twice the grading modulus plus 10, whichever is the higher value. LS shall not exceed 5 %. In the case of calcretes, the PI shalt not exceed 15, provided that the LS does not exceed 6 % and the product of the LS and the percentage passing the 0,425mm sieve does not exceed 320. | PI shall not exceed 12 or the value equal to 3 times the grading modulus plus 10, whichever is the higher value. In the case of calcretes, the PI shall not exceed 17, provided that the LS does not exceed 7 % and the product of the LS and the percentage passing the 0,425mm sieve does not exceed 320. |
| SIZE | - | | | | The maximum size of crushed material shall be 53 mm before compaction. The maximum size uncrushed material shall be 63 mm. | The maximum size of crushed material shall be 63 mm before compaction. The maximum size of uncrushed material shall be two-thirds of the compacted layer thickness. | The maximum size of crushed. material shall be 75 mm before compaction. The maximum size of uncrushed material shall be two-thirds of the compacted |
| SOLUBLE SALTS | See 3.3.5(a). | | | | See 3.3.5(a) | nrp | nrp |
| GRADING | See Table 8. | | | | The percentage (by mass) passing the 2,00mm sieve shall be not less than 20 % and not more than 70%. Grading modulus shall be not las than 1,5 and not | Grading modulus shall be not less than 1,2 and not more than 2,6. | Grading modulus shall be not less than 0,75 and not more than 2,7. |

# TABLE 3A AND 3B OF SANS 1200M:1996

## GRADING OF GRADED CRUSHED STONE (TABLE 8)

| | NOMINAL APERTURE SIZE OF SIEVE (mm) | PERCENTAGE PASSING SIEVE BY MASS | | | |
|---|---|---|---|---|---|
| | | G1, G2 and G3 C1 and C2 | G3 C1 and C2 | G4 | WM |
| | | 37.5mm | 37.5mm | 37.5mm | |
| GRADING | 75.0 | | | | 100 |
| | 53.0 | | | 100 | 85 - 100 |
| | 37.5 | 100 | 100 | 85 - 100 | 0 – 70 |
| | 26.5 | 84 - 94 | 84– 94 | 70 - 95 | 0 – 25 |
| | 19.0 | 71 - 84 | 71 - 84 | 60 - 90 | 0 - 5 |
| | 13.2 | 59 - 75 | 59 - 75 | 50 - 85 | |
| | 4.75 | 36 - 53 | 36 - 53 | 30 - 65 | |
| | 2.00 | 23 - 40 | 23 - 40 | 20 - 50 | |
| | 0.425 | 11 - 24 | 11 - 24 | 10 - 30 | |
| | 0.075 | 4 - 12 | 4 - 12 | 5 - 15 | |

## 10% FINES AGGREGATE CRUSHING VALUES (Table 4)

| Rock Type | Matrix | Dry (min.) | Wet (min.) | Wet / Dry (min.) |
|---|---|---|---|---|
| Arenaceous rocks | Non-siliceous cementing | 140kN | | 75% |
| | Siliceous cementing material | 110kN | | 75% |
| Diamictites (tillites) | | 200kN | | 70% |
| Argillaceous rocks | | 180kN | 125kN | - |
| Other rock types | | 110kN | | 75% |

## AGGREGATE CRUSHING VALUE (Table 5)

| Rock Type | ACV, max. |
|---|---|
| Arenaceous: without siliceous cementing matrix | 27% |
| Arenaceous: with siliceous cementing matrix | 29% |
| Diamictites (tillites) | 21% |
| Argillaceous rocks | 24% |
| Other rock types | 29% |

## DURABILITY REQUIREMENTS FOR G4 MATERIAL (Table 6)

| GROUP | MEMBERS OF GROUP | DURABILITY MILL INDEX (MAX.) | % PASSING 0.425mm SIEVE AFTER DURABILITY MILL TEST (MAX.) |
|---|---|---|---|
| Basic crystaline rock | Basalt<br>Dolerie<br>Gabbro | 125 | 35 |
| Acid crystaline rock | Gneiss<br>Granite | 420 | 35 |
| High silica rock | Chert<br>Hornfels<br>Quartzit | 420<br>(clay mineral kaolin) | 35 |
| Sandstone | Arkose<br>Conglomerate<br>Sandstone<br>Siltstone | 125 | 35<br>(increase from original not more than 15%) |
| Mudrock | Mudrock<br>Phylitte<br>Shale etc | 125 | 35 |
| Carbonate rock | Dolomite<br>Limestone<br>Marble | not applicable | not applicable |
| Diamictities | Greywacke<br>Tillite | 125 | 35 |
| Pedogenic material | Calcrete<br>Ferricrete<br>Silcrete | 480 | 40 |

# Appendix C
# Structural Defects of Houses in Various Areas

# Free State Province

# Gauteng Province

# Appendix D
# Example of Standardised Specifications

# Appendix D1
# Standardised Specification for Townships and Housing

Drafted by Professor Peter Day and Keshia Myburgh (candidate)

SAICE GEOTECHNICAL DIVISION

PART 1: STANDARDISED SPECIFICATION

for

GEOTECHNICAL INVESTIGATIONS

**A: HOUSING AND TOWNSHIP DEVELOPMENT**



# 1. SCOPE AND PURPOSE

This specification covers geotechnical investigations for township development and house foundations. It lists the minimum requirements for such investigations within the framework of existing national and industry standards.

The purpose of this specification is to provide a standardised means of incorporating the requirements for geotechnical investigations into tenders and contract documentation.

# 2. INTERPRETATIONS

## 2.1 NORMATIVE REFERENCES

2.1.1 The **latest edition** of the following standards shall form part of the contract document:

a) SANS 634: Geotechnical investigation for Township Development
b) SANS 10160-5: Basis of structural design and actions for buildings and industrial structures, Part 5: Basis for geotechnical design and actions.
c) SANS 10400-H: Application of the National Building Regulations, Part H: Foundations.
d) SAICE (2007) Code of Practice: The safety of men working in small diameter shafts and test pits for geotechnical engineering purposes. SAICE Geotechnical Division, 2007.
e) NHBRC *Home building manual*. National Home Builders Registration Council, Johannesburg.

2.1.2 On dolomite land, the latest edition of the following additional standards shall form part of the contract document:

a) SANS 633: Soil profiling and rotary percussion borehole logging on dolomite land in Southern Africa for engineering purposes.
b) SANS 1936-1: Development of dolomite land, Part 1: General principles and requirements.
c) SANS 1936-2: Development of dolomite land, Part 2: Geotechnical investigations and determinations.

2.1.3 Soil profiling and rock logging shall be carried out in accordance with one or more of the following standardised procedures:

a) Jennings J.E., Brink A.B.A. and Williams A.A.B. (1973) Revised Guide to Soil Profiling for Civil Engineering Purposes in South Africa. *The Civil Engineer in South Africa*, January 1973.
b) S.A. Section of the Association of Engineering Geologists. (1976) A Guide to Core Logging for Rock Engineering. *Symposium on Exploration for Rock Engineering*, Johannesburg, November 1976.

c) Brink A.B.A. and Bruin R.M.H. (eds) (1990) Guidelines for Soil and Rock Logging in South Africa, 2nd Impression 2002. *Proc. Geoterminology Workshop*. SAIEG - AEG - SAICE 1990.

## 2.2 APPLICATION

2.2.1 This specification is applicable to geotechnical investigations for township development and housing. Particular requirements for the application of this specification are given in Part 2: Project Specification.

## 2.3 DEFINITIONS

The definitions given in the normative references (see 2.1) and the following additional references shall apply:

Atterberg Limits: transition points between various states of soil consistency, namely the liquid limit, plastic limit and shrinkage limit.

Collapse potential test: Standard oedometer test in which a sample of potentially collapsible soil is loaded initially at natural moisture content to 200kPa and then saturated under load followed by one further load increment prior to unloading the sample.

Collapsible soil: soil with a high void ratio and low density that, when subjected to a combination of additional loading and an increase in moisture content, experiences sudden or rapid settlement.

Compressible soil: soil that, when subject to loading, undergoes gradual settlement as volume changes occur.

Double oedometer test: Standard oedometer tests carried out on two specimens of soil from a single undisturbed sample at natural moisture content and soaked conditions respectively.

Expansive soil (heaving soil): fine grained soil the clay mineralogy is such that it changes volume to varying degrees in response to changes in moisture content, i.e. the soil increased on volume (heaves or swells) upon wetting and decreases in volume (shrinks) upon drying out.

Modified oedometer test: Standard oedometer test in which a sample of expansive soil is loaded initially at natural moisture content to a predetermined pressure and then saturated under load followed by completion of the normal loading cycle.

Oedometer test: Laboratory test for investigating the one-dimensional consolidation of soils.

Problem soils: soils are volumetrically unstable or prone to subsidence or erosion including collapsible soils, compressible soils, heaving soils, dispersive soils, soft clays and dolomite land.

Soil classification tests: Determination of the particle size distribution of soils by means of sieve analysis and hydrometer testing combined with the determination of Atterberg limits.

## 2.4 ADDITIONAL REFERENCES

2.4.1 The following additional references are recommended for guidance but do not form part of this specification unless specifically referenced:

a) SAICE (2010). *Site Investigation Code of Practice*. Geotechnical Division, SAICE.

b) NHBRC: *A guide to the Home Building Manual*, National Home Builders Registration Council, Johannesburg.

## 3. GEOTECHNICAL CATEGORY OF DEVELOPMENT

3.1 The requirements for geotechnical investigations, design of geotechnical works, supervision of construction and monitoring shall be in accordance with the requirements set out in Section A.3 of SANS 10160-5 for the appropriate category of development.

3.2 Unless otherwise stated in the Project Specification, the following geotechnical categories shall apply:

a) Geotechnical Category 1: Detached or attached homes not exceeding three stories on site class designations R, H, H1, C, C1, S and S1 as defined in SANS 10400-H.

b) Geotechnical Category 2: All township investigations and attached or detached homes not exceeding three stories on any site class designation with the exception site class designation P (SANS 10400-H) or dolomite area designations D3 and D4 in accordance with SANS 1936-1.

c) Geotechnical Category 3: Developments exceeding ten stories high or developments situated on site class designation P (SANS 10400-H) or dolomite area designations D3 and D4 (SANS 1936-1).

## 4. REQUIREMENTS FOR GEOTECHNICAL INVESTIGATIONS FOR TOWNSHIP DEVELOPMENT

### 4.1 General

4.1.1 Geotechnical investigations for township developments shall be carried out in accordance with the requirements of SANS 634.

4.1.2 On dolomite land, additional investigations shall be carried out in accordance with SANS 1936-2.

4.1.3 The nature and extent of any geotechnical constraints (see SANS 634, Table 1) shall be quantified during the township investigation such that:

a) the investigation required for individual housing units for the purposes of NHBRC site classification is limited to confirmation of the geotechnical conditions over the upper 2m of the soil profile; and

b) the quantitative information in the form of laboratory or field test results provided by the township investigation, together with information from the investigation of the soil conditions over the upper 2m on the site of the individual housing unit, is sufficient for the design of the foundations for the unit.

### 4.2 Additional Requirements

In addition to the above, the following requirements shall apply:

4.2.1 The depth of investigation shall be such that the ground properties below the depth of investigation will have no influence of the performance of the foundations. In particular, on sites underlain by expansive clays, the full thickness of the expansive layer shall be investigated at sufficient locations to define the extent of the expansive material in both depth and area. The base of the expansive layer shall be taken as the bottom of the clay layer or the depth to the permanent water table.

4.2.2 The volume change potential of heaving and collapsible shall be determined using tests that directly measure the volume change of the soil on wetting such as the collapse potential test, modified oedometer test or the double oedometer test. These tests shall be supplemented by soil classification tests.

4.2.3 On sloping ground where there is potential for slope instability, the depth of investigation shall be such that any potential zones along which shear fail may occur in the soil or rock profile are identified and mapped.

## 5. REQUIREMENTS FOR INDIVIDUAL HOUSING UNITS

5.1 In townships investigated in accordance with SANS 634

The following requirements apply in areas investigated in accordance with SANS 634 including the requirements of 4.1:

5.1.1 The competent person responsible for the classification of soil conditions on the site of individual housing units shall:

a) obtain a copy of the township geotechnical investigation report and asses the adequacy of its contents and applicability to the development site,
b) investigate by means of one or more test pits the soil conditions over the upper 2 m of the soil profile, or until stable material is reached,
c) ensure that the profile observed in the test pits accords with the findings of the township investigation report,
d) take such samples and carry out such testing as may be required from the upper 2m of the profile to determine the founding characteristics of the near-surface soil profile, and
e) classify the site the soil conditions on the site in accordance with the findings of the test pits and the information from the township development report.

5.1.2 In the case of Geotechnical Category 3 developments (see 3.2) or in cases where the profile observed in the test pits does not accord with the findings of the township geotechnical investigation report, further investigations shall be carried out in accordance with the requirements of 4.1.3 and 4.2.

5.2 In townships not previously investigated

5.2.1 In the case of areas not previously investigated in accordance with SANS 634 including the requirements of 4.1, further investigations shall be carried out in accordance with the requirements of 4.1.3 and 4.2.

5.3 Infill development and rezoning or subdivision of existing stands

5.3.1 In the case of infill development and rezoning or subdivision of existing stands, the competent person responsible for the classification of soil conditions on the site of individual housing units shall comply with the procedures set out in 5.1.1 and 5.1.2.

## 6. REQUIREMENTS FOR COMPETENT PERSONS

6.1 Competent persons shall conform to the following requirements:

a) the requirements of 3.6 of SANS 634 in the case of township geotechnical investigations,
b) the requirements of the NHBRC home building manual in the case of individual housing units, and
c) the requirements of 3.2 of SANS 1936-2 for infrastructure development on dolomite land.

6.2 For Geotechnical Category 3 developments (see 3.2), the appointed competent person shall be:

a) registered as a Professional Engineer or a Professional Engineering Technologist with the Engineering Council of South Africa, or

b) registered as a Professional Natural Scientist with the South African Council for Natural Scientific Professions, and

c) have suitable experience in geotechnical site investigations.

PART 2:

GUIDELINES FOR PREPARATION OF PROJECT SPECIFICATIONS

for

GEOTECHNICAL INVESTIGATIONS



## A: HOUSING AND TOWNSHIP DEVELOPMENT

## 1. SCOPE AND PURPOSE

1.1 The application of the Standardised Specification given in Part 1 requires additional project specific information to be provided (see 2.2.1 of Part 1).

1.2 The purpose of Part 2 is to provide guidance to the person responsible for compiling the tender of contract documentation on essential data to be provided in the Project Specification. It also provides guidance on additional clauses which may be required for specific projects.

## 2. ESSENTIAL DATA

2.1 Site data

2.1.1 Township investigations

The following essential site data should be provided for township geotechnical investigations:

a) Registered property name, e.g. farm number, portion number and district.
b) Location, extent and property boundaries including details of any servitudes.
c) Contour plans of the site, unless site survey is to form part of the investigation. This data should preferably be provided in AutoCad or similar electronic format.
d) Existing development and services.
e) Details of previous land use.
f) Restricted areas of the site such as environmentally sensitive zones, heritage areas and graveyards.
g) Any previous geotechnical investigations or knowledge of problem soil conditions.
h) Any specific requirements imposed by local (or other) authorities regarding the investigation of the site.
i) Access restrictions.

2.1.2 Housing unit investigations

The following essential site data should be provided for the investigation of individual housing units:

a) Registered property name, e.g. erf number, township and if applicable, street address.
b) Location, extent and property boundaries including details of any servitures.
c) Contour plans of the site, unless site survey is to form part of the investigation.
d) Details of existing development and services.
e) Details of previous land use.
f) Any previous geotechnical investigations including township geotechnical investigation report or knowledge of problem soil conditions.

g) Any specific requirements imposed by local (or other) authorities with regard to the investigation of the stand.

2.2 Proposed development

2.2.1 The nature of the proposed development affects the Geotechnical Category of the site and land use category required for the application of SANS 1936-1 or the NHBRC Home Building Manual. It also determines any specific requirements associated with the proposed development such as movement tolerance of foundations, foundation loading, etc.

2.2.2 The following essential site data should be provided on the proposed development:

a) For township geotechnical investigations:
   - Proposed density of development in terms of units per hectare of average size of individual stands.
   - Intended land use, e.g. low-cost housing, mixed use development, lifestyle estate, etc.
   - Nature of structures including attached / detached, number of stories, unconventional construction materials, etc.
   - Preliminary township layout plans (if available).

b) For township geotechnical investigations:
   - Layout / architectural plans of proposed development.
   - Any special requirements from the structural designer, e.g. settlement tolerances, bearing pressures below large bases, etc.

     Note: The NHBRC requirement is damage to the structure should be no more than Damage Category 1 (very slight). If a different damage category is required, this must be specified.

## 3. ADDITIONAL CLAUSES AND AMENDMENTS

3.1 Additional clauses

3.1.1 Where the standardised specification does not adequately define the investigation requirements, additional clauses may be added. These clauses should preferably be numbered in to follow the last sub-clause in each section of Part 1.

3.1.2 Additional clauses may include:

a) Responsibility for detection, location protection of existing services.
b) Responsibility for provision of services for investigation, e.g. water for drilling.
c) Specific requirements for rehabilitation of test positions.
d) Responsibility for notifications to the Department of Labour.
e) Employer's safety specification in terms of the Occupational Health and Safety Act.

   Note: Commercial terms such as method or measurement and payment, limitations of liability, indemnities, etc. are best included in the professional services agreement under which the professional responsible for the investigation is appointed rather than in the project specification.

3.2 Amendments

3.2.1 Amendments to the standardised specification are best given in tabular form in which the clause number and the proposed amendment are listed.

# Appendix D2
# Standardised Specification for Excavations and Lateral Support

Drafted by Mrs Nanine Fouché, Keshia Myburgh (candidate) and Professor Peter Day

SAICE GEOTECHNICAL DIVISION

PART 1: STANDARDISED SPECIFICATION

for

GEOTECHNICAL INVESTIGATIONS

**B: EXCAVATIONS AND LATERAL SUPPORT**



## 1. SCOPE AND PURPOSE

This specification covers geotechnical investigations for excavations and lateral support. It lists the minimum requirements for such investigations within the framework of existing national and industry standards.

The purpose of this specification is to provide a standardised means of incorporating the requirements for geotechnical investigations into tenders and contract documentation.

## 2. INTERPRETATIONS

2.1 Normative References

2.1.1 The latest edition of the following standards shall form part of the contract document:

a) SANS 10160-5: Basis of structural design and actions for buildings and industrial structures, Part 5: Basis for geotechnical design and actions.
b) SABS 1200-D: Standardized specification for civil engineering construction, Part D: Earthworks.
c) SAICE (1989) -Code of Practice: Lateral support in surface excavations. SAICE Geotechnical Division, 1989.

2.1.2 Soil profiling and rock logging shall be carried out in accordance with one or more of the following standardised procedures:

a) Jennings J.E., Brink A.B.A. and Williams A.A.B. (1973) Revised Guide to Soil Profiling for Civil Engineering Purposes in South Africa. The Civil Engineer in South Africa, January 1973.
b) S.A. Section of the Association of Engineering Geologists. (1976) A Guide to Core Logging for Rock Engineering. Symposium on Exploration for Rock Engineering, Johannesburg, November 1976.
c) Brink A.B.A. and Bruin R.M.H. (eds) (1990) Guidelines for Soil and Rock Logging in South Africa, 2nd Impression 2002. Proc. Geoterminology Workshop. SAIEG - AEG - SAICE 1990.

2.2 Application

2.2.1 This specification is applicable to geotechnical investigations for excavations and lateral support. Particular requirements for the application of this specification are given in Part 2: Project Specification.

2.3 Definitions

The definitions given in the normative references (see 2.1) and the following additional definitions shall apply:

Atterberg Limits: Transition points between various states of soil consistency, namely the liquid limit, plastic limit and shrinkage limit.

Dolomite Residuum: Residual soils, including chert and dolomite gravel and boulders, derived from the decomposition of dolomite.

DPSH: Dynamic probe super heavy.

Investigation Point: A point on the site where the soil and rock profile, and the properties of the ground are determined to at least the depth of the rockhead including boreholes, auger holes, static or dynamic soil probing or trial pits.

Permanent Excavation or Permanent Lateral Support: Excavations and lateral support required to ensure stability and satisfactory service performance of the permanent structure or excavation.

Soil classification tests: Determination of the particle size distribution of soils by means of sieve analysis and hydrometer testing combined with the determination of Atterberg limits.

Temporary Excavation or Temporary Lateral Support: Excavations and lateral support required during the construction phase of a project for a period not exceeding 2 years.

Unstable Ground: Ground that is not capable of supporting itself over an unsupported height of 1,5m and dolomite residuum.

2.4 Additional References

2.4.1 The following additional references are recommended for guidance but do not form part of this specification unless specifically referenced:

a) SAICE (2010). Site investigation Code of Practice. Geotechnical Division, SAICE.
b) Byrne, G and Berry, A.D. 2008. A guide to practical geotechnical engineering in Southern Africa. 4th Ed. Johannesburg: Franki Africa.

3. GEOTECHNICAL CATEGORY OF DEVELOPMENT

3.1 The requirements for geotechnical investigations, design of geotechnical works, supervision of construction and monitoring shall be in accordance with the requirements set out in Section A.3 of SANS 10160-5 for the appropriate category of development.

3.2 Unless otherwise stated in the Project Specification, the following geotechnical categories shall apply:

a) Geotechnical Category 1: Temporary excavations less than 2m deep in stable ground above water table or which are battered to a stable angle. No lateral support required.
b) Geotechnical Category 2: Temporary or permanent excavations less than 10m deep in ground above the water table, the sides of which are battered to a stable angle or require lateral support.

c) Geotechnical Category 3: Temporary or permanent excavations deeper than 10m, excavations in unstable ground or ground below the water table.

## 4. REQUIREMENTS FOR GEOTECHNICAL INVESTIGATIONS FOR EXCAVATIONS AND LATERAL SUPPORT

### 4.1 General

4.1.1 Geotechnical investigations for excavations and lateral support shall be carried out in accordance with the requirements of SAICE (1989) and the requirements of this standardised specification.

4.1.2 On dolomite land, additional investigations shall be carried out in accordance with SANS 1936-2.

4.1.3 Quantitative data for design of excavations and lateral support is required for all categories of excavations except Geotechnical Category 1 excavations.

4.1.4 Classification of the excavatibility of material shall be in accordance with SABS 1200-D.

### 4.2 Extent of Investigation

4.2.1 The depth of investigation shall be such that the ground properties below the depth of investigation will have no influence on the design of the lateral support system.

4.2.2 In soft soils where overall instability of the sides of the excavation or heave of the excavation floor could occur, the depth of investigation shall be sufficient to determine the properties of the soils to the depth required for the assessment of these potential failure mechanisms. This depth may be as much as one excavation width below the proposed excavation depth.

4.2.3 Irrespective of the nature of the ground, the depth of investigation shall not be less than the proposed depth of the excavation including any sumps, foundation excavations, pile caps, lift pits or other localised excavations.

4.2.4 During the detailed phase of the investigation, a minimum of one investigation point per 400m$^2$ shall be achieved. At least half of these shall extend to the depth of investigation required by 4.2.1 to 4.2.3. Where significant changes in ground properties or in bedrock depth are observed, the number of excavation points should be increased.

4.2.5 Where the lateral support system includes anchors or soil nails extending beyond the perimeter of the excavation and where there is a possibility that the conditions outside the excavation perimeter may differ from those within the excavation, additional investigation shall be carried out in the anchored zone. This applies particularly to sites adjacent to geological contacts, faults and dykes or other intrusions.

### 4.3 Methods of Investigation

4.3.1 The method of investigation at each investigation point shall be capable of determining the nature of the ground profile, the properties of the ground whether by in situ measurements or by retrieving of samples for laboratory testing, and the depth of the water table. Such methods include rotary core boreholes, auger holes, trial pits and piezocone testing.

4.3.2 Methods of investigation such as DPSH tests that are not capable of determining the nature of the ground profile shall not be regarded as investigation points unless it can be reliably shown that the ground profile is uniform over the area of the site in question. In any event, the ration of such tests to investigation points employing investigation methods in compliance with 4.3.1 shall not exceed one in two.

4.4 Essential Data

4.4.1 Except to the extent permitted by 4.3.2, the data at each investigation point shall include:

a) A complete description of the soil and rock profile in accordance with the references given in 2.1.2.
b) Depth of the permanent and perched water tables, if any.
c) Results of in situ tests and details of any samples taken, if any.

4.4.2 With the exception of Geotechnical Category 1 excavations, the investigation shall provide the following geotechnical parameters for each layer within the soil profile:

a) Grading (including determination of clay fraction) and Atterberg Limits.
b) Bulk density, specific gravity and moisture content.
c) Compressibility of soil.
d) Shear strength of soil in terms of effective strength parameters.
e) Undrained shear strength where appropriate
f) In the case of permanent lateral support, an assessment of the corrosivity of the ground.

In the case of Geotechnical Category 2 excavations, geotechnical parameters may be determined from test results, either directly or through correlation, theory or empiricism, and from other relevant data. For Geotechnical Category 3 excavations, geotechnical parameters shall be determined from appropriate laboratory tests or from the results of in situ tests.

## 5. REQUIREMENTS FOR COMPETENT PERSONS

5.1 The investigation shall be undertaken under the control of a Competent Person who:

a) is registered in terms of the Engineering Profession Act, 2000 (Act No. 46 of 2000), as either a Professional Engineer or a Professional Engineering Technologist, and has a tertiary qualification (degree or diploma) in geotechnical engineering, or
b) is registered in terms of the Natural Scientific Professions Act, 2003 (Act No. 27 of 2003), as a Professional Natural Scientist, and has a BSc (Hons) degree or higher qualification in engineering geology, and
c) is generally recognized as having the necessary experience and training to undertake rational assessments in the field of geotechnical engineering and engineering geology.

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## B: EXCAVATIONS AND LATERAL SUPPORT

## 1. SCOPE AND PURPOSE

1.1 The application of the Standardised Specification given in Part 1 requires additional project specific information to be provided (see 2.2.1 of Part 1).

1.2 The purpose of Part 2 is to provide guidance to the person responsible for compiling the tender of contract documentation on essential data to be provided in the Project Specification. It also provides guidance on additional clauses which may be required for specific projects.

## 2. ESSENTIAL DATA

2.1 Site data

2.1.1 Investigations for excavations and lateral support

The following essential site data should be provided for geotechnical investigations for excavations and lateral support:

a) Registered property name, e.g. erf number and street address.
b) Location, extent and property boundaries including details of any servitudes.
c) Contour plans of the site, unless site survey is to form part of the investigation. This data should preferably be provided in AutoCad or similar electronic format.
d) Existing development and services both on and around the site.
e) Details of previous land use.
f) Any previous geotechnical investigations or knowledge of problem soil conditions.
g) Any specific requirements imposed by local (or other) authorities or neighbouring land owners regarding the investigation of the site.
h) Access restrictions.

2.2 Proposed development

2.2.1 The following essential data should be provided on the proposed development:

a) Nature of the proposed works.
b) Structural and architectural requirements / plans.
c) Depth and extent of the proposed excavation.
d) Type of temporary and permanent support envisaged.
e) Permissible movements of adjacent structures / services.
f) Extent of monitoring requirements.

# 3. ADDITIONAL CLAUSES AND AMENDMENTS

## 3.1 Additional clauses

3.1.1 Where the standardised specification does not adequately define the investigation requirements, additional clauses may be added. These clauses should preferably be numbered in to follow the last sub-clause in each section of Part 1.

3.1.2 Additional clauses may include:

a) Responsibility for detection, location protection of existing services.
b) Responsibility for provision of services for investigation, e.g. water for drilling.
c) Specific requirements for rehabilitation of test positions.
d) Responsibility for notifications to the Department of Labour.
e) Employer's safety specification in terms of the Occupational Health and Safety Act.

Note: Commercial terms such as method or measurement and payment, limitations of liability, indemnities, etc. are best included in the professional services agreement under which the professional responsible for the investigation is appointed rather than in the project specification.

## 3.2 Amendments

3.2.1 Amendments to the standardised specification are best given in tabular form in which the clause number and the proposed amendment are listed.

# Appendix D3
# Standardised Specification for Pile Foundations

Drafted by Keshia Myburgh (candidate) and Professor Peter Day

SAICE GEOTECHNICAL DIVISION

PART 1: STANDARDISED SPECIFICATION

for

GEOTECHNICAL INVESTIGATIONS

# **C: PILE FOUNDATIONS**

## 1. SCOPE AND PURPOSE

This specification covers geotechnical investigations for pile foundations. It lists the minimum requirements for such investigations within the framework of existing national and industry standards.

The purpose of this specification is to provide a standardised means of incorporating the requirements for geotechnical investigations into tenders and contract documentation.

## 2. INTERPRETATIONS

### 2.1 Normative References

2.1.1 The latest edition of the following standards shall form part of the contract document:

a) SANS 10160-5: Basis of structural design and actions for buildings and industrial structures, Part 5: Basis for geotechnical design and actions.

2.1.2 Soil profiling and rock logging shall be carried out in accordance with one or more of the following standardised procedures:

a) Jennings J.E., Brink A.B.A. and Williams A.A.B. (1973) Revised Guide to Soil Profiling for Civil Engineering Purposes in South Africa. *The Civil Engineer in South Africa*, January 1973.
b) S.A. Section of the Association of Engineering Geologists. (1976) A Guide to Core Logging for Rock Engineering. *Symposium on Exploration for Rock Engineering*, Johannesburg, November 1976.
c) Brink A.B.A. and Bruin R.M.H. (eds) (1990) Guidelines for Soil and Rock Logging in South Africa, 2nd Impression 2002. *Proc. Geoterminology Workshop*. SAIEG - AEG - SAICE 1990.

2.1.3 On dolomite land, the latest edition of the following additional standards shall form part of the contract document:

a) SANS 633: Soil profiling and rotary percussion borehole logging on dolomite land in Southern Africa for engineering purposes.
b) SANS 1936-1: Development of dolomite land, Part 1: General principles and requirements.
c) SANS 1936-2: Development of dolomite land, Part 2: Geotechnical investigations and determinations.
d) Additional References

2.1.4 The following additional references are recommended for guidance but do not form part of this specification unless specifically referenced:

a) SAICE (2010). *Site Investigation Code of Practice*. Geotechnical Division, SAICE.
b) EUROCODE 7: BS EN 1997-1:2004 Geotechnical Design – Part 1: General rules.

c) EUROCODE 7: BS EN 1997-2:2007 Geotechnical Design – Part 2: Ground Investigation and Testing.
d) Franki Africa (2008). A guide to practical geotechnical engineering in Southern Africa. 4th Ed. December 2008. Franki Africa, Johannesburg.

2.2 Application

2.2.1 This specification is applicable to geotechnical investigations for piled foundations. Particular requirements for the application of this specification are given in Part 2: Project Specification.

2.3 Definitions

The definitions given in the normative references (see 2.1) and the following additional references shall apply:

Atterberg Limits: Transition points between various states of soil consistency, namely the liquid limit, plastic limit and shrinkage limit.

CPT, CPTu: Static cone penetration test without and including pore water pressure measurements respectively.

Investigation Point: A point on the site where the soil and rock profile, and the properties of the ground are determined to at least the depth of the rockhead or the likely pile founding depth.

Soil classification tests: Determination of the particle size distribution of soils by means of sieve analysis and hydrometer testing combined with the determination of Atterberg limits.

SPT: Standard penetration test.

3. GEOTECHNICAL CATEGORY OF DEVELOPMENT

3.1 The requirements for geotechnical investigations, design of geotechnical works, supervision of construction and monitoring shall be in accordance with the requirements set out in Section A.3 of SANS 10160-5 for the appropriate category of development.

3.2 Unless otherwise stated in the Project Specification, the following geotechnical categories shall apply:

a) Geotechnical Category 1: Vertically loaded piles in stable ground supporting relatively simple structures where the adequacy of the bearing stratum can be assessed from the description of the soil profile. No exceptional loading or settlement limitations and negligible risk of pile failure or excessive settlement.
b) Geotechnical Category 2: Piles or pile groups supporting conventional structures where the assessment of pile capacity and pile head displacements involves the application of well-established design methods based on the results of routine in situ or laboratory testing. No exceptional loading or difficult ground conditions.
c) Geotechnical Category 3: Piles, pile groups and piled rafts subject to high vertical or horizontal loads or in difficult ground conditions requiring specialist geotechnical input.

# 4. REQUIREMENTS FOR GEOTECHNICAL INVESTIGATIONS PILE FOUNDATIONS

## 4.1 General

4.1.1 Geotechnical investigations for pile foundations shall be carried out in accordance with the requirements of SAICE (2010) Site Investigation Code of Practice.

4.1.2 Quantitative data for the assessment of pile capacity and displacements is required for all categories of piled foundations except Geotechnical Category 1 foundations.

4.1.3 On dolomite land, additional investigations shall be carried out in accordance with SANS 1936-2.

## 4.2 Extent of Investigation

4.2.1 The depth of investigation shall be such that the ground properties below the depth of investigation will have no influence of the performance of the piles.

4.2.2 Irrespective of the nature of the ground, the depth of investigation shall not be less than the likely founding depth of the piles plus a minimum of six pile diameters.

4.2.3 Below buildings or other developments with closely spaced points of load application, a minimum of one investigation point per $400m^2$ shall be achieved. At least half of these shall extend to depth of investigation required by 4.2.1 or 4.2.2.

4.2.4 Below bridge foundations or other widely spaced points of load application, a minimum of two investigation points per foundation shall be achieved. All investigation points shall extend to depth of investigation required by 4.2.1 or 4.2.2. Additional investigation points may be required depending on the extent of the foundation and the variability of the profile.

4.2.5 In instances where significant changes in ground properties or in bedrock depth is observed, the number of investigation points should be extended/increased.

## 4.3 Methods of Investigation

4.3.1 The method of investigation shall be capable of investigating the ground conditions to the depths required by 4.2.1 or 4.2.2. Typical methods of investigation include rotary core drilling, auger hole drilling, often combined with in situ testing such a static and dynamic probing.

4.3.2 The method of investigation shall be capable of providing quantitative data required for the design of the piles by means of in situ testing or retrieving samples for laboratory testing or both.

4.3.3 For major projects in difficult or unfamiliar ground conditions, the installation and testing of trial piles may be considered.

## 4.4 Essential Data

4.4.1 Data at each investigation point shall include:

a) A complete description of the soil and rock profile in accordance with the references given in 2.1.2.
b) Depth of the permanent and perched water tables, if any.
c) Depth, thickness, extent and permeability of water-bearing strata in the ground.
d) The presence, classification and distribution of identified obstructions such as boulders, well-cemented pedocretes, etc.

4.4.2 With the exception of Geotechnical Category 1 foundations, the investigation shall quantify the soil parameters required for the design of the piled foundations as listed below.

a) For the assessment of pile capacity by calculations based on ground strength parameters: Drained and/or undrained shear strength (as appropriate) of soil and the unconfined compressive strength and rock mass classification of rock for all horizons contributing to the capacity of the pile:

b) For the assessment of pile capacity based on in situ test results: Profiles of in situ test results such as CPT or CPTu, SPT or pressure meter tests.

c) For the assessment of pile settlement or lateral movement: profiles of in situ tests or stiffness parameters for the soil or rock mass determined by in situ or laboratory tests.

d) For the assessment of downdrag or uplift forces due to soil displacement around the pile shaft, where applicable: stiffness and shear strength parameters of the unstable soil horizons and any overlying horizons.

4.4.3 In the case of Geotechnical Category 2 foundations, geotechnical parameters may be determined from test results, either directly or through correlation, theory or empiricism, and from other relevant data. For Geotechnical Category 3 excavations, geotechnical parameters shall be determined from appropriate laboratory tests or from the results of in situ tests.

## 5. REQUIREMENTS FOR COMPETENT PERSONS

5.1 Competent persons shall conform to the following requirements:

a) the requirements of 3.2 of SAICE (2010) Code of Practice in the case of pile foundations.

b) the requirements of 3.2 of SANS 1936-2 for development on dolomite land.

5.2 For Geotechnical Category 3 developments (see 3.2), the appointed competent person shall be:

a) registered as a Professional Engineer or a Professional Engineering Technologist with the Engineering Council of South Africa, or

b) registered as a Professional Natural Scientist with the South African Council for Natural Scientific Professions, and

c) have suitable experience in geotechnical site investigations.

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## C: PILE FOUNDATIONS



## 1. SCOPE AND PURPOSE

1.1 The application of the Standardised Specification given in Part 1 requires additional project specific information to be provided (see 2.2.1 of Part 1).

1.2 The purpose of Part 2 is to provide guidance to the person responsible for compiling the tender of contract documentation on essential data to be provided in the Project Specification. It also provides guidance on additional clauses which may be required for specific projects.

## 2. ESSENTIAL DATA

2.1 Site data

2.1.1 The following essential site data should be provided for geotechnical investigations done for pile foundations:

a) Registered property name, e.g. erf number and street address.
b) Location, extent and property boundaries including details of any servitudes.
c) Contour plans of the site, unless site survey is to form part of the investigation. This data should preferably be provided in AutoCAD or similar electronic format.
d) Accessibility and constraints on site.
e) Existing development and services.
f) Details of previous land use, where disturbance of the natural ground conditions may have taken place.
g) Restricted areas of the site such as environmentally sensitive zones, heritage areas and graveyards.
h) Any previous geotechnical investigations or knowledge of problem soil conditions.
i) Any specific requirements imposed by local (or other) authorities regarding the investigation of the site.

2.2 Proposed development

2.2.1 The nature of the proposed development affects the Geotechnical Category of the site and land use category required for the application of SANS 1936-1. It also determines any specific requirements associated with the proposed development such as movement tolerance of foundations, foundation loading, etc.

2.2.2 The following essential site data should be provided on the proposed development:

a) Nature of the proposed development, e.g. high-rise building, industrial structure, bridge, etc. including layout / architectural plans of proposed development.

b) Location of columns or points of load application to the foundations.
c) Magnitude of loads on the foundations.
d) Permissible movements.

## 3. ADDITIONAL CLAUSES AND AMENDMENTS

### 3.1 Additional clauses

3.1.1 Where the standardised specification does not adequately define the investigation requirements, additional clauses may be added. These clauses should preferably be numbered in to follow the last sub-clause in each section of Part 1.

3.1.2 Additional clauses may include:

a) Responsibility for detection, location protection of existing services.
b) Responsibility for provision of services for investigation, e.g. water for drilling.
c) Specific requirements for rehabilitation of test positions.
d) Accommodation of traffic, e.g. lane or road closures.
e) Responsibility for notifications to the Department of Labour.
f) Employer's safety specification in terms of the Occupational Health and Safety Act.

Note: Commercial terms such as method or measurement and payment, limitations of liability, indemnities, etc. are best included in the professional services agreement under which the professional responsible for the investigation is appointed rather than in the project specification.

### 3.2 Amendments

3.2.1 Amendments to the standardised specification are best given in tabular form in which the clause number and the proposed amendment are listed.